PART D
(ANNEX 3 about Smart Systems)

of the

2014 ECSEL MASRIA

2014 MultiAnnual Strategic Research and Innovation Agenda for the ECSEL Joint Undertaking

Elaborated for the Private Members Board of the ECSEL Joint Undertaking

by the EPoSS Industry Association

EPoSS
European Technology Platform
on Smart Systems Integration

Smart Systems in the Multi-Annual Strategic Research and Innovation Agenda of the JTI ECSEL

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1 Introduction

This chapter describes the basic assumptions by the EPoSS community on the opportunities and challenges of smart systems integration regarding the societal, economical and environmental development in Europe in general, and in view of the innovation driven objectives of Horizon 2020 in particular.

Smart Systems combine data processing with sensing, actuating and communication and are able to analyse complex situations and to take autonomous decisions. They take advantage of miniaturisation, and are often invisible to the consumer. They are highly energy efficient or even energy autonomous and can communicate with their environment. Smart Systems recognise each other and enable the product in which they are integrated to interact with the environment and with other “intelligent” systems. Their application may lead to improved safety in cars or to reduced emissions in transport, they can be used to help disabled people in their familiar environment by providing cognitive assistance or they can make buildings and manufacturing equipment more energy-efficient by orders of magnitude. Often the incorporation of Smart Systems will provide the key technical features for the competitiveness of products in all these sectors and more.

Smart Systems will provide solutions to address grand challenges and risks for mankind in social, economic and environmental terms. Examples of the threats we face are as follows:

- Pollution of the environment and depletion of energy and materials resources
- Aging populations and demographic change
- Fictitious value creation threatening real value creation
- Higher vulnerability of economies accompanying globalisation
- Risk of industrial decline and mass unemployment
- Destabilization of entire world regions and the increase of extremism and terrorism
- Increased needs for the mobility of people and goods
- Demand for fresh water and safe food
- Health risks resulting from lifestyle
- Limited access to energy sources and scarce materials

Many Information technology companies have identified up-coming “Smart Systems” as fundamental to their "Smarter Planet" campaigns which are aiming at providing smart technologies for intelligent resource-saving energy, sustainable transport and traffic, energy efficient buildings and intelligently managed municipalities. Major electrical engineering companies such as Siemens and General Electric are building upon Smart Systems for solutions in the healthcare and advanced manufacturing sector.

Europe - currently the global market leader in the field of Smart Systems - has both an excellent knowledge base as well as solid industrial structures and highly skilled workforce in this field – reason enough to further expand Europe’s competitive advantages and to strengthen its position in global terms. The excellence of European Smart Systems research is represented by a number of strong big players as Bosch, Siemens, Philips, ST Microelectronics, Thales and EADS forming a powerful technological backbone. High class public research structures (MPI, CEA LETI, FhG, IMTEK, CNM, CNRS), medium size private and public research entities as well as thousands of high-tech SMEs are forming a powerful backbone of excellence and creativity.

Therefore Smart Systems research has to be considered as one of the technology areas of primary importance for Europe, not least because:

In all competing world regions the importance of smart systems integration (SSI) as a fundamental cross-cutting technology has been recognised. U.S. companies as well the policy makers, also in China or Japan, consider smart system integration technologies as a condition for creating competitive advantages in a highly developed industrial environment. Powerful industrial competitors able to move with a high innovation speed are also able to exercise a significant price pressure. Competitive advantages go hand in hand with high investments of the public sector in these regions for both, R&D as well as manufacturing infrastructure. The technical requirements for complexity and diversity of functionalities for innovative product solutions powered by Smart Systems Integration are huge. They require an efficient and dynamic research and manufacturing infrastructure[1] and a comprehensive collaborative approach of the public and private sides. Europe has reached an outstanding level in mastering Smart Systems Integration Technologies, in companies as well as in research organisations and is holding the world market leader position. This is the basis to build upon for further developments in order to remain competitive with innovative products competitive in global markets.

1.1 Smart Systems Addressing Societal Challenges

Global markets with their changing dynamics have created an environment of worldwide competition. A series of social, economic and environmental factors concerning every nation, company or entity have become primary driving forces. Global competition for scarce resources, changing consumer and business behaviour, new technologies and changes of the institutional framework all lead to an increased innovation pressure on industry and also on the research community.

As recognised by most governments, technological development and innovation in the next few decades will be determined by major pace-setting challenges termed the "Big Five":

- Climate change and the environment
- Energy and resource conservation
- Health and an ageing population
- Transport and efficient mobility
- Safety and security

Smart Systems provide decisive solutions for current and emerging problems in all the above categories. They have enormous potential to benefit people's everyday lives and tackle society-wide challenges, not only in developed countries but also for less infrastructure intensive societies where the low cost adaptability and autonomous distributed intelligence featured by Smart Systems could provide affordable and readily-deployed solutions.

The Digital Agenda of the COM focuses already on technological capabilities to treat environment with respect, and to minimize GHG emissions, to reduce the energy consumption of processes, machines and buildings, to support ageing citizens' lives, to revolutionize health services and to deliver better public services at large. Smart Systems technologies can feature in all this, and furthermore drive forward concepts for sustainable mobility and measures for securing the integrity of data and the privacy of individuals.

The ability to adapt to and exploit change is pivotal for the competitiveness of the European economy and for achieving the EU's overall growth and job objectives. Policy measures can have significant impact on technology developments, and hence, have to support and stimulate restructuring processes and continuous adjustments to changing conditions. Through process and service innovations, totally new manufacturing processes or business models will be implemented: from new forms of energy storage to intelligent billing of the cost of medical services. The backbones of this coping strategy, however, are primarily products, innovative products manufactured in Europe which are able to revolutionise existing markets and open up new ones in multiple application fields.

As an important pool of cross-cutting technologies, smart system integration is core to Europe 2020: "To achieve a sustainable future, a mid-term perspective has to be developed. Europe needs to get back on track. Then it must stay on track. That is the purpose of Europe 2020. It's about more jobs and better living. It shows how Europe has the capability to deliver smart, sustainable and inclusive growth, to find the path to create new jobs and to offer a sense of direction to our societies."2

Smart Systems will provide answers and solutions to these challenges by supplying the enabling functionalities for innovative products and services in a timely, cost effective manner, and by serving user

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[1] According to IHS the world market leaders in manufacturing are based in Europe (http://press.ihs.com/press-release/design-supply-chain/its-tie-bosch-and-stm-hold-joint-honors-no-1-mems-suppliers-2012).

[2] José Manuel Durão Barroso, President of the European Commission, Communication from the commission: EUROPE 2020 - A strategy for smart, sustainable and inclusive growth, Preface, Brussels, 3.3.2010, COM(2010)2020

requirements beyond today's expectations. The following overview shows, functionalities, technological and innovation aspects of Smart System Integration and their interrelations at various levels in view of their contribution to societal challenges.

Smart Systems developments are driven by the user-level needs of individuals and society. Foresight and futures have, in different ways, been used to anticipate social changes. During the last 2-3 years, the term 'Grand Societal Challenges' has emerged (and has been promoted) as an appropriate phrase to capture some of the major issues facing people around the world during the next decades. 'Grand Societal Challenges' may be regarded as a significant discursive formation and infiltrated the discussions, at least in relevant policy communities as well as R&D and industry. This discourse tends to convey the scale and depth of challenges, a sense of interdependency of problems and the need for a concerted, strategic response. To be responsibly involved in this discourse, it seems to be necessary to analyse some recent developments, to find out, how European research and innovation systems can offer responses to emerging global challenges and opportunities.

Global challenges signal unprecedented change. This will take place at economic, social, political, ethical, regional as well as individual levels. It is the task of research and industry alike to analyse, based on their skills and potential, the problems arising from these challenges and changes, then to provide the functionalities needed for addressing these problems and to improve or develop the technologies for implementing these functionalities in marketable, affordable and competitive products. Smart Systems technologies are capable of providing the necessary solutions and opportunities. Some examples of this potential follow:

Example Climate: Governance of and influence upon the processes causing climate changes and stressing the environment require firstly a pool of excellent, scientifically exact and non-contradictory data. These have to be acquired using extensive in-situ and remote monitoring providing locally-relevant information and highly specific pollution sensing, possibly with automated counter-measures. Equipped with enhanced functionalities based on smart system solutions, these monitors will provide unique performance, with, for example, resilience to user errors and ability for de-skilled operation, autonomous intelligence, system-wide networking, evaluation of local conditions and contextually optimising the system-efficiency without the need for external control.

Example Energy: The increasing difficulties to economically access irreplaceable resources necessitate a conceptual rethinking of energy and resource use. Europe's dependencies upon energy sources such as gas or oil, or special materials such as platinum for catalysts or lithium for high-performance batteries or rare earths for high-efficiency electrical drives, high-efficiency light-converting phosphors or high-performance wind power generators must be seen as the primary driver for a number of strategically necessary developments in Europe. Sophisticated usage of energy and conservation of resources, supplemented by seeking alternatives, is the order of the day. We expect intelligence to be introduced at both module and system levels to manage and control energy consumption in specific environments (e.g., buildings, public spaces) as well as providing assistance to users to reach the goals of efficient energy consumption. The Smart system based solutions provide opportunities to use renewable energies as a pillar in a pan-European concept of secure energy supply by solving problems of safe, adaptive electricity storage at product, domestic and regional levels due to an interdisciplinary combination of properties of tailored materials with innovative seamless sensing, processing and actuation approaches to power management and distribution. Smart system integration is also a basic technology for a low waste, high efficiency production, for sophisticated facility management and a starting point for shrinking the use of scarce materials due to a holistic system integration approach.

Example Health: Population ageing, progressing rapidly in nearly all industrialised countries, is expected to be among the most prominent global demographic trends of the 21st century. This process is expected to continue over the next few decades, affecting one way or the other the entire world. Population ageing generates severe consequences for socio-economic development and public health, for example shrinking and ageing of the labour force, losses in innovative ability and the possible bankruptcy of social security systems.

Smart Systems integration is the basic technology promising solutions for advanced personalised point-of-care diagnosis and treatment to avoid enormous ramps in the cost of the social security and health system. With multiple sensing and an in-built facility to make deductions, Smart Systems have the potential to self-test, to self-calibrate and to shut down, reconfigure or self-heal in the case of fault or unexpected operating conditions. They can build a technological basis for advanced solutions for urgently needed ambient assisted living and mobility approaches. This will make it possible for millions of people to live in their home environment independently as long as possible, from social, economic, well-being and health points of view. Smart Systems solutions can provide higher performance from common and also new materials, by exploiting nano-, micro- and bio-technology to enable new adaptive prosthetics or artificial organs for vital replacements, acting as a bridging technology and adjunct to tissue engineering and other purely medical treatments.

Example Mobility: Individual mobility and public transportation systems will face many challenging issues in the future. Critical among these are the fuel and energy sources that will drive the vehicles, and the concomitant air pollutant and greenhouse gas emissions. There are several promising options: improving mainstream internal combustion engines and the gasoline and diesel fuels they utilise; propulsion system electrification using hybrid internal combustion engines, batteries, and electric motors, combinations in charge-sustaining and plug-in versions that draw electricity from the power grid; pure battery/motor electric drive systems; natural gas fuelled vehicles; and fuel-cell powered vehicles operating on hydrogen. Another area of concern is road safety and the losses in productivity by time wasted in congestion. A promising path to overcome these issues is provided by the networking and automation of the vehicle, which at the same time would serve the need for energy efficient traffic solutions. The enabling technologies for automation are driver assistance systems, advanced intelligent lighting systems, environment perception, as well as control and communication systems based on smart systems integration.

For all of these examples, Smart Systems provide basis technologies to solve the challenges which these techniques bring with them.

1.2 Smart Systems: a Chance for Europe

In the last decade, Smart Systems Integration has undoubtedly matured into one of the most important enabling technologies, now guaranteeing the world market success of innovative products in numerous and different application fields. These cover a wide range of opportunities, from intelligent implants and pacemakers in medical technology to Smart Systems in the automotive industry, where they add to the efficiency of propulsion technologies while also increasing the safety of occupants. Smart Systems in intelligent industrial control systems help reduce the CO2 emissions enormously. They make aviation safer, and allow for the detection of hazardous and harmful substances in safety and security applications.

Many of these applications have their origin in Europe. European industry has achieved a market leading position in many fields - not least because of the continued support at national and European level.

Due to their technological and innovation capabilities, as well as their customer focus, Europe's Smart Systems manufacturers currently enjoy a good competitive position in many Smart Systems segments. Process knowledge and application know-how ensure that, worldwide, customers can expect the best fitting technology tailored to their specific needs. The European Smart Systems sector is characterised by representing nearly all the necessary technologies and disciplines. The very specialised sensor sector alone consists of more than 6,000 innovative companies in EU27. Total employment in the Smart Systems sector amounts to 827,600 employees in 2012 of which 8%, i.e. 66,200 are employed in R&D activities. R&D expenditures are 9.6 B€.[3]

The Smart Systems sector in Europe is also characterised by high value creation and a highly-skilled workforce. It is an excellent example of a competitive European value chain. Despite a high degree of

[3] Sources: Prognos AG: Analyse zur ökonomischen Bedeutung der Mikrosystemtechnik, Studiums about the Smart Systems economy in Baden-Württemberg and Germany; European Competitiveness Report; EU Industrial Structure 2011; Figures provided by major industry associations.

automation, human system know-how is still essential to make the best connections between devices and the applications environment they are incorporated in. Moreover, the legal and environmental conditions under which products are made are becoming increasingly important to the customer. European manufacturers enjoy also an excellent reputation in both these matters.

In recent years the speed of development has increased significantly because of the immediate and expected economic benefits and the great potential of the technology. However, along the way new questions for the direction and focus of future research efforts have come in view. The interdisciplinary nature of Smart Systems development and integration is a weighty issue. New tailor-made and multi-functional materials promise the provision of entirely new properties, the integration of bio-components are beginning to blur the barriers between living and dead matter. The design, manufacture, testing and assurance of the smooth running of these systems will engender methods and tools with not yet foreseeable challenges. This leads to a need of highly sophisticated R&D, as well as a need of bringing different disciplines together and for the matching and the advantageous usage of different scientific and technological approaches; including advanced manufacturing capabilities as a base for commercialisation of the results.

The tackling of all these tasks will increasingly over-strain the performance of individual economies. The U.S. was, due to the generous support of DoD, DoE, NSF, or DARPA, a leader in the use of SSI technology in military and security technology. The resulting developments demonstrated to have an enormous potential for civilian applications. Dual use constitutes for the U.S. economy a significant competition factor. Stakeholders in Japan, China and Korea focus their efforts on the other hand on the use of Smart Systems technology to strengthen their already claimed application fields, such as the consumer sector, and continue to set themselves apart from the competition with innovative developments.

Thus it is of high importance to favour every initiative, which can help Europe to maintain industrial leadership at all stages of the value added chain in the smart system domain.

1.3 Smart Systems and Key Enabling Technologies

Smart Systems bridge the gap from the component to the product.

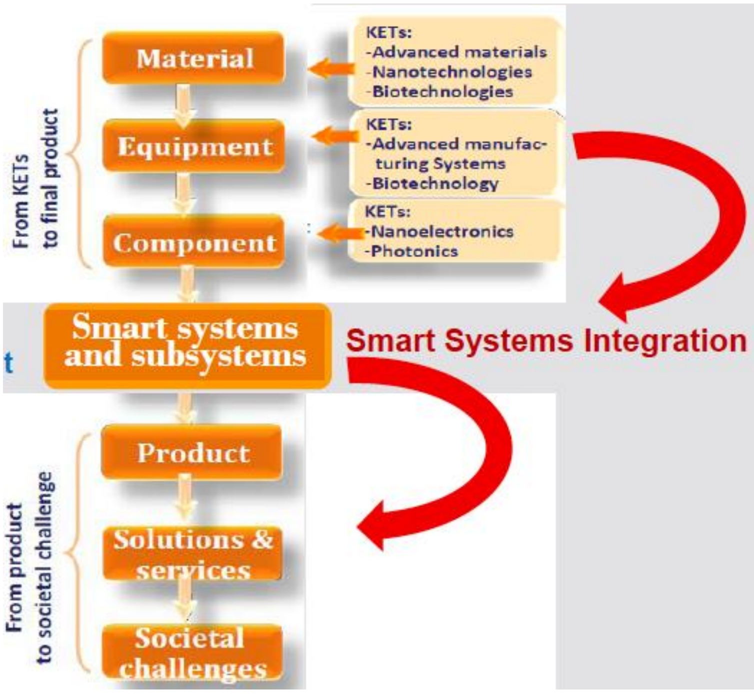

Figure: *Smart Systems in the context of the KET concept*

2 Strategic Research

In this chapter, the structure of the Strategic Research Agenda of EPoSS, which is annexed to the MASRIA, is explained, and the successful implementation of EPoSS priorities in the ICT work programmes and funded projects of the European Commission's Seventh Framework Programme for Research (FP7) is referenced.

2.1 Structure of the EPoSS SRA

Since the founding of EPoSS in 2005, a major activity of the ETP has consisted in the development and implementation of roadmaps and a Strategic Research Agenda (SRA) on Smart Systems Integration (SSI) in application fields that are important for the European SSI community.

EPoSS has been a pioneer with respect to its SRAs, in that already the first SRA edition published in 2007, and since then both the second edition in 2009 and the latest edition in 2013 were not purely technology-driven like the SRAs of many other platforms, but structured according to key application sectors for Smart Systems Integration, and providing roadmaps for medium and long-term research needs not only in terms of technologies and functionalities, but also in terms of applications and markets. Thereby it acknowledges and clearly addresses the connection between Smart Systems and the application sectors that they serve.

Equally since the beginnings of EPoSS, these roadmaps recognise the 3-generations-concept of Smart Systems, see chapter 3.

The latest edition of the SRA, published in 2013, is annexed to this document. It looks towards 2020+, based upon expert information contributed by the members of EPoSS, and the wider SSI community. It describes the current status and future prospects for Smart Systems in terms of technologies, functionalities and markets in 32 subsectors within 7 applications sectors (see **Fehler! Verweisquelle konnte nicht gefunden werden.** and **Fehler! Verweisquelle konnte nicht gefunden werden.**), and three further transversal domains (see **Fehler! Verweisquelle konnte nicht gefunden werden.**) that underpin the development, production and use of Smart Systems.

The SRA forecasts the introduction of the three generations of Smart Systems across all of the subsectors, analyses the European strengths, weaknesses, opportunities and threats regarding Smart Systems across each sector and transversal domain, and as a result puts forward priority actions, mid-term and longer term research priorities.

The SRA is a clear statement of technology and market categories, it records questions, barriers, difficulties and opportunities, provides a checklist with timescales and forecasts for researchers and strategists in SMEs, Large Companies and RTOs, serves as discussion paper to support dialogues with government, and with funding and regulatory bodies.

Above all, the SRA is a reference document upon which to base action, within individual organisations (industry, research and academia), within SSI clusters and networks, within the overall SSI ecosystem in Europe, cross-business, cross-region, between EU and Member States and on an international level.

Consequently the SRA has not only served as basis for the EPoSS input to the Smart Systems objective in the ICT part of the new Leadership in Enabling and Industrial Technologies (LEIT) Work Programme, but also for the development of the Smart Systems part of the ECSEL JTI's MASRIA.

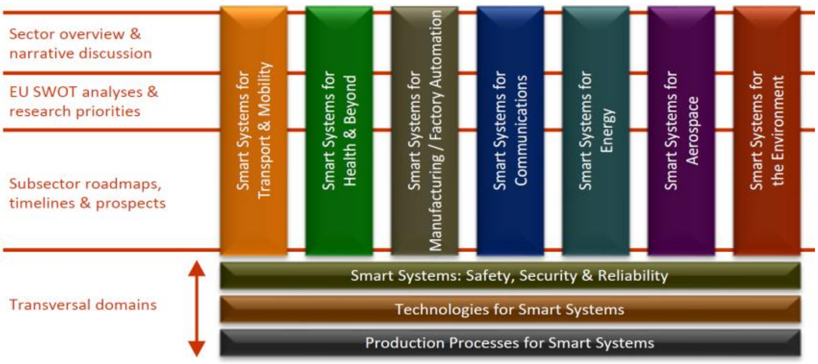

Figure 1: Structure of the Strategic Research Agenda of EPoSS

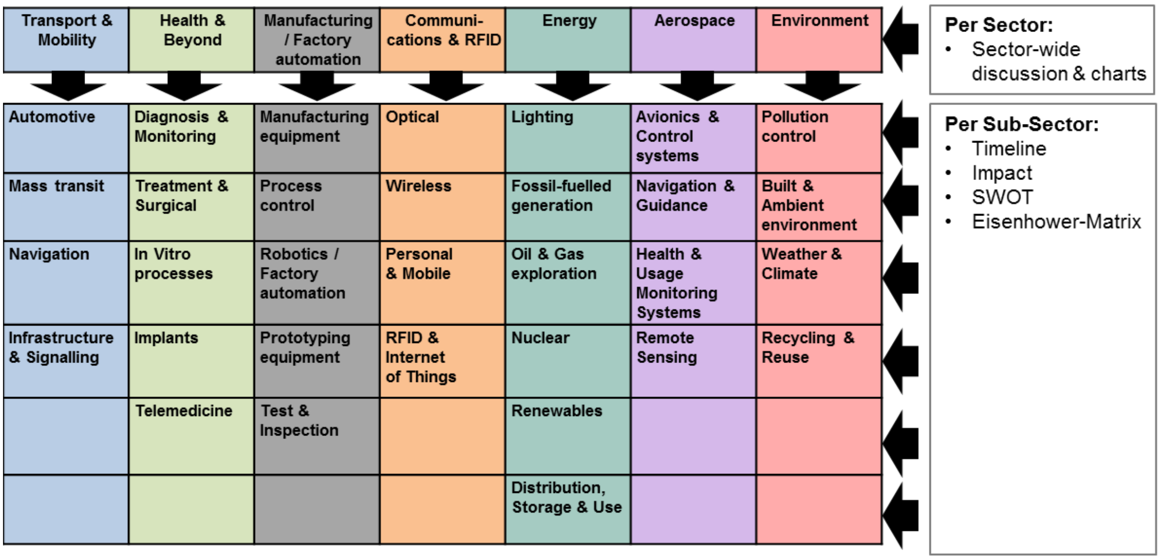

Figure 2: Sectors and subsectors covered in the SRA

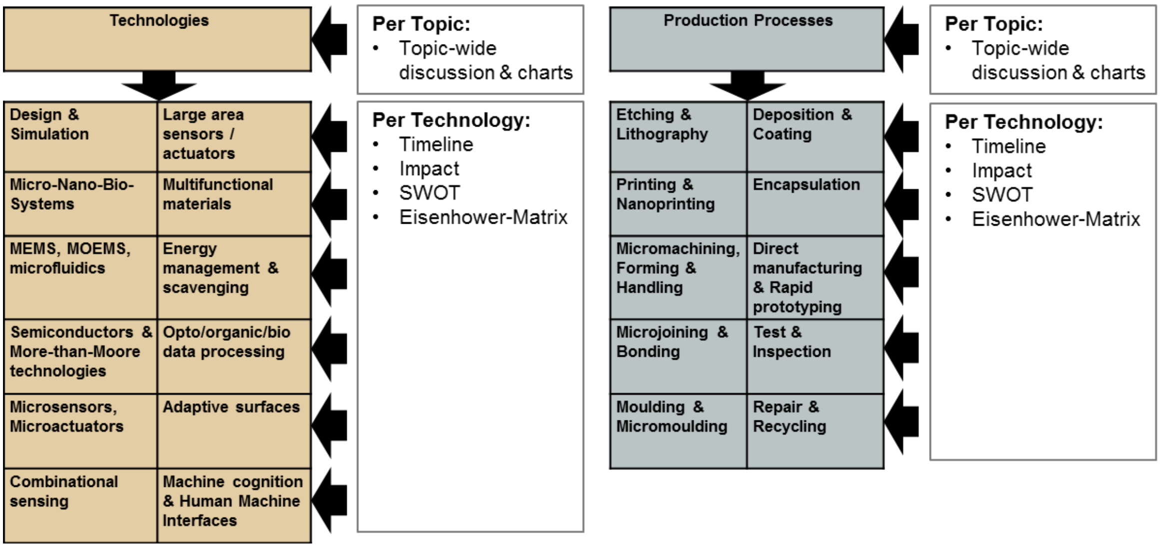

Figure 3: Technologies and Production Processes covered in the SRA

2.2 Implementation in FP7 Work Programmes

The research priorities, roadmaps and SRAs developed by the experts involved in EPoSS have served as valuable basis for input to FP7, covering the policy, priority, Work Programme and Call Fiche levels and targeting also structural and operational issues such as Public Private Partnerships (PPP).

Based on the 2007 and 2009 editions of the SRA, EPoSS provided input to relevant challenges and objectives of the ICT Work Programmes in FP7, the primary target being the **core objectives, exclusively dedicated to Smart Systems Integration** (previously titled Micro/nanosystems, Smart Miniaturised Systems, or Smart Components and Systems) and Micro-Nano-Bio Systems of the respective FP7 ICT Work Programmes 2007-2008, 2009-2010, 2011-2012 and 2013. For these objectives alone, the European Commission provided a total of **312 M€** funding between 2007 and 2013 through 5 dedicated calls (ICT Calls 2, 5, 7, 8 and 10).

Further to this, EPoSS – again based on the SSI roadmaps and SRAs – has significantly contributed to building and shaping the **European Green Cars PPP** as well as the **Internet of Things objectives** in the ICT Work Programmes. The reason for the major role EPoSS has played in the European Green Cars PPP and the Internet of Things is that SSI is a cornerstone for innovative solutions in these topics. In driving these topics, both on a policy and priority level, EPoSS has managed to secure additional funding for SSI specific projects and hence for the SSI community, worth **481 M€** in FP7 through ICT Calls 1, 4, 5, 6, 7, 8 and 10 as well as through the dedicated Green Cars calls.

Last, but not least, to give a complete picture of the implementation of EPoSS research priorities in FP7 ICT Work Programmes, it has to be said that many **additional objectives** address technologies and solutions specific to SSI, and consequently provide additional opportunities for the SSI community. Examples of such relevant objectives are cognitive systems and robotics, electronics integration, electronic-based miniaturised systems, organic and large-area electronic systems, photonic systems, personal health systems for monitoring and point-of-care diagnostics, ICT and ageing, Smart Factories, and manufacturing solutions for new ICT products. The budget allocated for these FP7 ICT Work Programme Objectives amounts to **1,895 M€**.

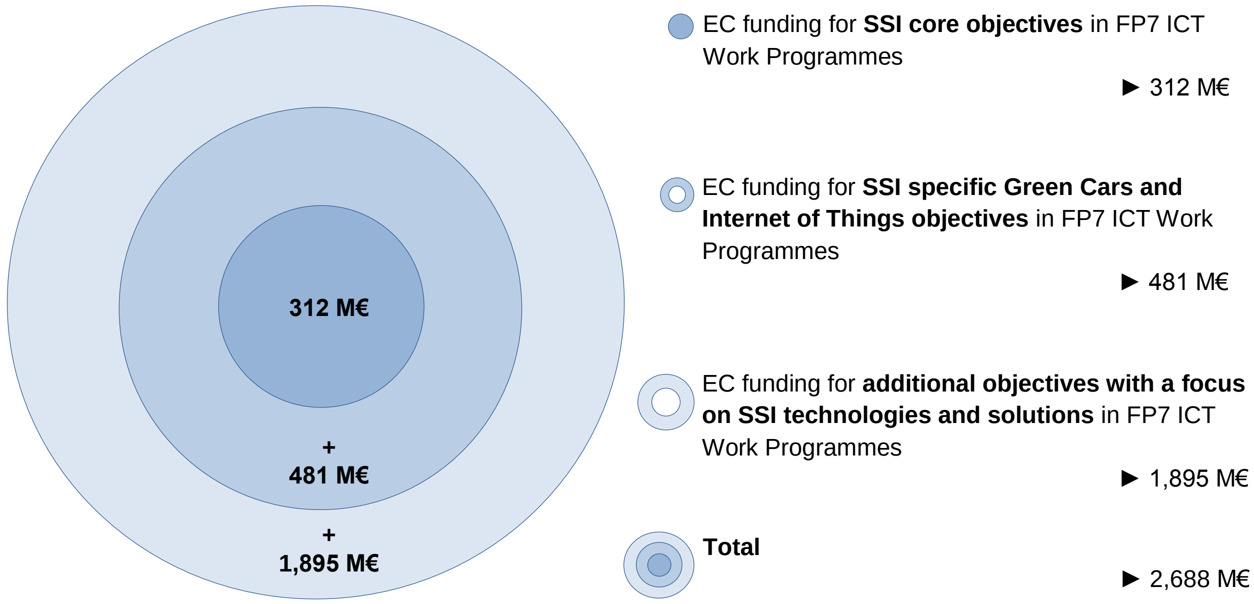

Figure 4: EC Funding for Smart Systems Integration in FP7 ICT Work Programme.

When looking at the budget of 2,688 M€ allocated to SSI research in FP7 ICT Work Programmes (see Figure 4) it becomes clear that SSI is an important research topic in FP7. This success is directly linked to the excellent road mapping and research agenda development performed by the experts involved in EPoSS.

Another success is the securing of funding for research projects in which EPoSS members are involved as contractual partners, and often even as coordinators. When analysing the funded projects originating from the core SSI objectives in FP7 ICT Work Programmes, it was found that between 35% and 50% of the funding for the total of 109 active SSI projects in FP7 (see **Fehler! Verweisquelle konnte nicht gefunden werden.**[4]) goes to EPoSS members.

SSI project clusters	Active projects
1. Smart Systems Integration	31
2. Micro-Nano-Bio Systems	18
3. Communications for Smart Systems	17
4. Integration and Manufacturing	4
5. Smart Fabrics and Interactive Textiles	3
6. ICT for the Fully Electric Vehicle	36
Total	**109**

Table 1: SSI project clusters and active projects per cluster

[4] According to their thematic focus, the funded projects originating from the core SSI objectives in FP7 ICT Work Programmes were clustered into 6 categories by the responsible unit at DG CONNECT (Cfr. http://cordis.europa.eu/fp7/ict/components/projects-fp7_en.html and http://www.green-cars-initiative.eu/public/documents/Project_Portfolio_EGCI_Calls_2010_2013_web.pdf).

3 Smart Systems: Functions and Technologies

This section explains the building blocks of smart systems, and the particular role of functionalities in linking base technologies and applications. Furthermore, the concept of smartness is explained in terms of gernations.

3.1 Smart Systems Building Blocks

Smart Systems are self-sufficient intelligent technical (sub-)systems with advanced functionality. They sense, diagnose, describe, qualify and manage a given situation in order to perceive complex circumstances, be predictive, and take autonomous decisions. Their operation is further enhanced by their ability to mutually address, identify and work in consort with each other. They are able to interface, interact and communicate with users, their environment and with other Smart Systems, and to manage their energy consumption.

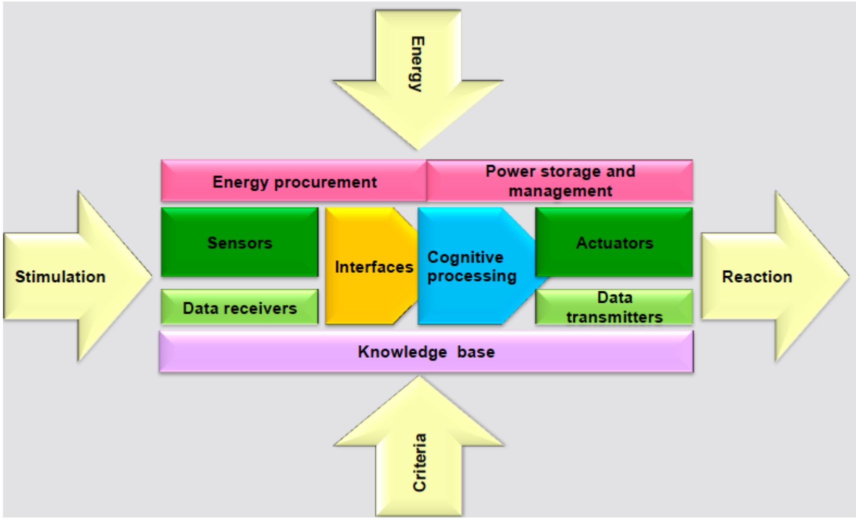

Figure: Building blocks of smart systems

Smart Systems can be standalone, networked, or embedded into larger systems; they comprise heterogeneous devices combining data processing with sensing, actuating, energy scavenging, and communication (see figure) and they excel in self-reliance and adaptability. What distinguishes smart systems from systems which are purely reactive is the knowledge base.

The development of Smart Systems requires the integration of inter-disciplinary knowledge from a manifold of enabling principles including nanoelectronics, micro-electro-mechanics, biosystems technologies, magnetism, photonics, chemistry, radiation and a multitude of other physical or chemical principles.

3.2 Development Process : Focus on Functionalities

Smart Systems developments are ultimately driven by the application to user-level needs of individuals and society. They identify the key systems functionalities to address those needs and marshal the most appropriate technologies in combinations to enable those functionalities (see Figure). By emphasizing functionalities, this development process is quite distinct from the alternative and typical route in non-smart development, which drives upwards from component level, often testing and conflicting with technology boundaries.

The major application fields for Smart Systems are in (e)wellness, (e)health and medicine, automotive and land/sea transportation, aerospace, safety and security, agriculture and food supply, energy conversion and management, storage and distribution, manufacturing, logistics and ICT. Smart Systems will enable and bring forward the technology breakthroughs needed to address the developing issues of public health and an aging population, environmental protection and climate change, the conservation of energy and scarce materials, enhancements to safety and security and the continuation and growth of economic prosperity.

The “smartness” of systems is expressed in autonomous and transparent operation based on closed loop control, predictive capabilities, energy efficiency and wider networking. Further typical functionalities of Smart Systems are e.g. reliable, intelligent, self-managed, expert and adaptable principles which are attentive to the needs, habits and capabilities of the user. Thus, the ever improving performance of signal processing technologies is transferred into smart systems, and the smart functionality is embedded into the very fabric of products, the built environment and its infrastructure. Eventually, the interaction between mankind and technology is improved through establishing smart human-machine interfaces.

In terms of the technology base Smart Systems can be considered as the consequent further development and future path of microsystem technology – including specialties such as MEMS, NEMS or MOEMS and RF MEMS. While microsystems are defined as miniaturised systems combining the sensing of physical, chemical or biological parameters, signal processing and actuators, Smart Systems are advanced technical systems with additional and highly advanced functionalities as described. Therefore, to enable the functionalities of Smart Systems one has to unlock the immense potential of new materials, effects and developments in combinations, across disciplines and magnitudes of scale bridging from nano- through micro- to macro-, to include multi-functional and composite materials, micro-, nano- and bio- technologies, multi-domain communications, signal processing and machine cognition. Linking technology between the nano-, micro- and macro-world systems integration is the key challenge. In this context, a particular relevance is to be attributed to Micro-Nano Bio Systems (MNBS) given their growing importance for various application sectors. MNBS are understood as Smart Systems combining microsensing and microactuation, microelectronics, nano-materials, molecular biology, biochemistry, measurement technology and ICT.

Ultimately, Smart Systems Integration will provide the functional connection of devices and subsystems at the component level (manufacturing), at the system level (integration into a macro system, or “handling level“), at the application level (integration into the overall system, or “product level“) and at the process level (integration of manufacturing processes including design, simulation, verification and testing). Systems integration may be based on monolithic, hybrid, multi-chip module or other techniques spanning several scales ranging in size from nano to micro to macro. These developments include also an impetus of electronic components development leading to smart components which demonstrate enhanced performance and functionality enabled by the re-use of nanoelectronics processes and building blocks offering very advanced performance, high voltage and high power operation or operating under special conditions.

3.3 The Evolution of Smart Systems

The progressive development of Smart Systems is characterised by their increasing autonomy through the twin effects of becoming increasingly self-sufficient in energy requirements and becoming less reliant upon external supervision and control. Advancements in the „smartness“ of a system are determined by the degree to which the key functionalities are implemented. The EPoSS community has defined the evolution of smart systems as follows:

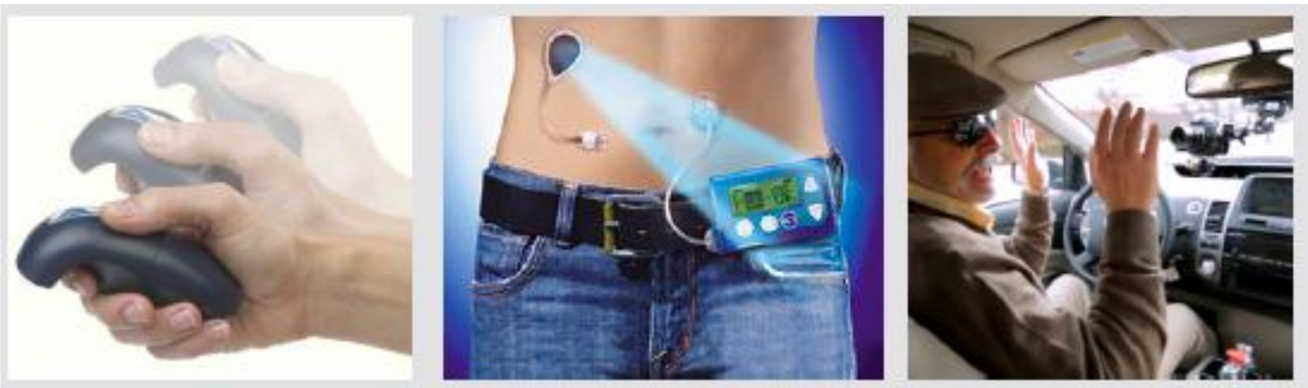

Figure: Evolution of smart systems: gyro mouse (1st generation), continuous glucose monitoring system (2nd generation), fully automated car (3rd generation)

1st Generation Smart Systems integrate sensing and or actuation as well as signal processing to enable actions. Such Smart Systems are already routinely and successfully deployed in many sectors. One simple example is a gyro mouse translating 2 axis hand movements into cursor positioning (see figure). Other examples are systems able to monitor the health status of persons and to initiate necessary actions, pacemakers and safety systems in automotive applications, as exemplified by airbag systems and electronic stability techniques for chassis frames.

2nd Generation Smart Systems are built on multifunctional perception and are predictive and adaptive systems with self test capabilities that are able to match critical environments. Moreover they are equipped with network facilities and advanced energy scavenging and management capabilities. Systems of this generation are able to measure and deal with variability and uncertainty, yet generate an informed suggestion in the decision-preparing process regarding the original sample and the multitude of answers required by the detection objective. They will be more and more featured with the ability to learn and adapt, to change environmental conditions, and to respond accordingly. A striking example of a 2nd generation Smart System is a continuous glucose monitoring system for patients with diabetes which is measuring subcutaneous fluid parameters, predicting the blood sugar trends and warning the user to take action. Cross disciplinary development of 2nd generation Smart Systems will furthermore bring about simple artificial organs and in-body implants that work with the body chemistry rather than guarding themselves against it as is the case with conventional heart pacemakers. Other examples of such systems include smart RFID labels with measurement of multiple parameters like temperature, inclination and shock for transport monitoring have already been introduced into market.

3rd Generation Smart Systems perform human-like perception and autonomy and generate energy. The Smart Systems of this generation act independently and do not require any human control or decision. They may also be able to establish self-organizing communication networks and develop from self-test to self-calibration and self-healing. A prominent example of a 3rd generation Smart System is a highly or fully automated car which is executing steering, acceleration and deceleration autonomously, monitoring the driving environment by itself, and either needs the driver not at all or just as a backup. Other free-ranging systems e.g., autonomous bio-robots and swarming agents interacting between the physical and virtual world, are at the far end of this vision.

It is important to understand that the generations of smart systems develop at different speed depending on the functionality considered. In many cases, the further optimization of 1st generation Smart Systems still requires serious research and development efforts. Overcoming the scientific, materials and manufacturing hurdles presented by 2nd and 3rd generation Smart Systems, however, will give Europe a critical technology lead. Generating a comprehensive approach to their design will ensure not just a single range of competitive products, but the ability and agility to maintain that competitive edge into the future.

4 Functionalities and R&D Requirements

Smart systems achieve functionality through the unique combination of their components, or building blocks. Some generic functionalities that are key for a multitude of applications as well as the timeframe of the related R&I efforts will be discussed in the following section. The base technologies to be developed for implementing those functionalities are described in chapter 6.

Sensors and actuators enable smart systems to interact with their environment. Depending on the complexity of the sensing task at hand, smart systems can detect physical, chemical or biological signals directly or remotely, or they can use multiple-parameter, autonomous, networked or nomadic sensing to acquire data on their environment. **Sensing** functionality is essential for a range of applications, such as in aeronautics, automotive transport, environmental monitoring, structural monitoring, manufacturing, and healthcare. Determining their location and recognizing their environment enables smart systems to gain autonomy, e.g. for automated transport or manufacturing. The reliable monitoring of body parameters, on the other hand, is not only important for monitoring the operator of a machine or the driver of a car, but also a key ingredient for applications in healthcare, where sensor networks may be used. Improvements in multiple-parameter sensing are required for the sensitive and selective detection of biochemical analytes, as well as for quality assurance in manufacturing and environmental monitoring. Lastly, novel remote sensing schemes can provide safe and non-intrusive access to harsh or complex environments.

The other means of interaction – **actuation** – allows smart systems to directly influence their environment. Actuators will increasingly have to operate in a wireless fashion, particularly in distributed smart systems or remote applications. Applications in aeronautics and automotive transport require faster, fail-safe motion control. Research on precise positioning methods, on the other hand, is essential for healthcare, smart prosthetics or manufacturing applications. Surface actuation and adaption schemes need to be developed to improve the performance and comfort of aeronautic and automotive systems, or to provide haptic feedback in human-machine interfaces. Finally, the ability to controllably release liquids or gases is essential for many smart systems in healthcare and manufacturing.

Sensing and actuation functionalities enabling 1st generation smart systems need to be continuously improved and extended to new parameters. Therefore, they remain a research and innovation topic for the entire duration of Horizon 2020. At the same time, their capabilities of handling multiple parameters and tasks need to be developed. Research and innovation for these functionalities will also play a major role in 3rd generation smart systems during the second half of the considered time frame when autonomous systems reach maturity. This expected progress is summarized in the roadmap shown in the figure below. Comparable considerations lead to the other roadmaps shown in this chapter.

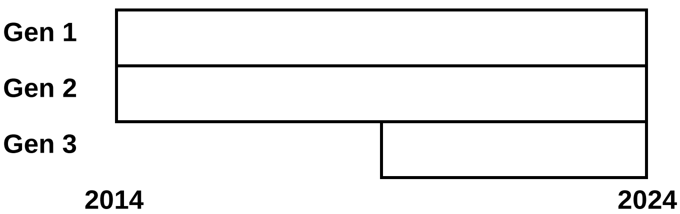

Figure: Progress of R&I in sensing and actuation.

Even when no direct actuation is required, smart systems usually still need to **interface** the outside world. Thermal, mechanical and electric contacts need to be developed. Research on the organic/inorganic interface (e.g., for diagnostics and prosthetics) is particularly important for applications in healthcare, as is the ability to safely implant and operate such systems in the (human) body. Apart from the body, future smart systems also have to be able to withstand other harsh environments, for example unusual levels of pressure, temperature, vibration, and radiation in aeronautic, automotive and manufacturing applications. Such adverse conditions may also require the development of more robust ways of communicating. Improved augmented reality solutions that facilitate human-machine interaction need to be developed for all application fields, e.g., for vehicle control and for assisted surgery.

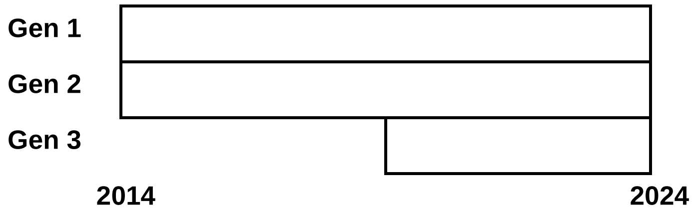

Figure: Progress of R&I in interfaces.

To extract information from external signals that are, for example, obtained through sensor components, smart systems need to be able to process such data. Research on **signal processing** is required to recognize patterns in optical and other data and to form a digital representation of their environment using as little computing power as possible. Such functionality can be important in automotive, aeronautic, healthcare or manufacturing applications. In addition, smart systems that operate in complex environments such as in air and road traffic or around the human body require more effective data fusion to process signals from several sensors. Improved closed-loop control circuits can enable such systems to react to these signals through, for example, actuators for motion control. Improvements in **cognitive processing** with functionalities such as dynamic and adaptive data processing, data analysis, environment recognition, machine learning, decision making and prediction are essential for applications in autonomous automotive and aeronautic systems, but also for improved manufacturing as well as for healthcare.

Figure: Progress of R&I in signal and cognitive processing.

The depth of integration and the degree of autonomy of smart systems depends strongly on progress in energy procurement, storage and management. Improvements in electrical, thermal and mechanical **energy management** are essential in all fields, but particularly in automotive and aeronautic applications as well as distributed or autonomous smart systems, where energy is scarce. Research on **energy generation and scavenging** can alleviate such energy scarcity, for example for applications in healthcare and environmental sensors.

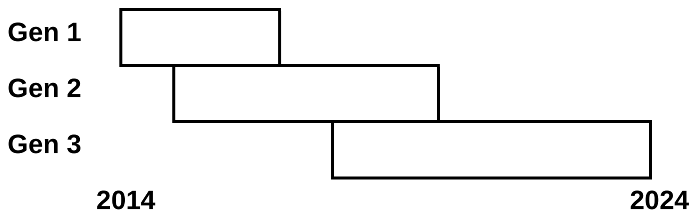

Figure: Progress of R&I in energy management and scavenging.

To exchange data with other systems in their vicinity, smart systems use receivers and transmitters. Energy efficient and robust **communication** is particularly important in harsh environments, for example, in aeronautic and automotive engineering or in particular applications in manufacturing and environmental monitoring. Research on **networking** and cooperation is required to enable distributed applications in aeronautics, automotive engineering, healthcare and environmental monitoring, such as sensor networks. Easy integration into the Internet of Things requires plug-and-play solutions. Smart systems for some applications in healthcare and other fields also need to be able to form body area networks. With increasing degree of autonomy, research on the dynamic integration of such systems, or rather, nomadic devices, in existing swarms will be necessary.

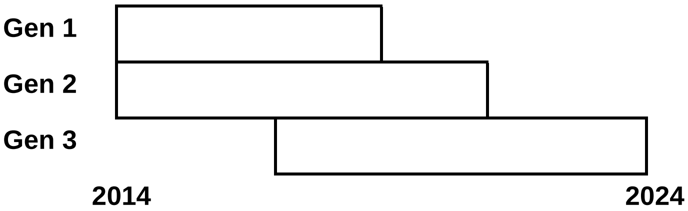

Figure: Progress of R&I in communication and networking.

In analyzing data, smart systems need to draw upon their **knowledge base**. Improvements in functionalities such as accessing existing data can be important for applications in healthcare, environmental monitoring or manufacturing – essentially anywhere where comparisons with previous situations have to be made. For applications in aeronautics and automotive, progress in mapping, positioning and targeting is crucial.

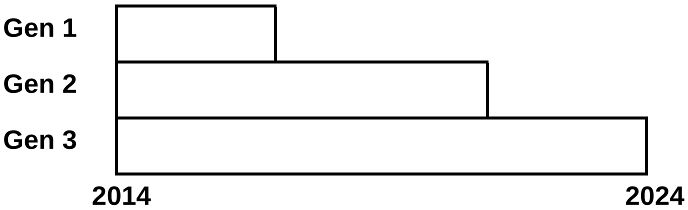

Figure: Progress of R&I in knowledge bases.

In summary, widely improved functionalities and new technologies will be required to enable the further evolution of smart systems towards higher degrees of utility, complexity, miniaturization, energy efficiency and autonomy. The clear research roadmap of EPoSS will help the European industry to achieve this end in a more time- and cost-efficient manner and enable consumers to benefit from smart functionality in everyday life.

5 Applications-specific Developments

Some smart systems functionalities that are specific and exclusive for particular applications are highligthed in this section, thus complementing the discussion of generic functionalities in the previous chapter.

5.1 Health

A specific and promising application of Smart Systems in the health domain can be expected from the extended use of current and future ICT-products to improve health as support for continuous monitoring or access to medical data or companion for long-term treatments e.g. smart watches that can sense pulse, smart phones with front camera able to monitor and analyse eye movements, touch screens recognising users' patterns and that can give a feedback on potential neurological disturbances.

Generally, numerous smart systems advances in the field of healthcare could be pictured in the concept of a "smart operating room", built as unique combination of smart systems functionalities for specific applications.

The smart operating room is the site where for instance smart implants or artificial organs for which predictive and adaptive components are needed, are being implanted into the body or used as replacement of body's function during surgery. Bioreactors, in which the environment is regulated by smart systems for an optimised cells or tissues growth are directly installed on-site for post-operative tissue reconstruction.

Surgery in the smart operating room is minimally invasive and made possible thanks smart functionalities related to robots for precision and remote surgery as well as to the combinations of imaging/diagnostics and therapy, e.g. in an endoscope or a smart pill.

Also assistance systems for the doctor greatly benefit from smartness, e.g. functionalised surgery tools building on real time analysis and guidance by imaging, and the interactive access to information provided by augmented reality, knowledge, and monitoring data.

Nevertheless, health applications of smart systems do imply further issues concerning notably the regulatory framework, including clinical tests, that have to be addressed before successful deployment. Ethical and reimbursement issues are also topics to be taken into account when developing smart systems for health applications as they may encompass matters such as accessibility to all, improvement of human capacities or the question of who is the end-user / end-payer. These topics have thus to be integrated into the development cycle from the beginning to increase the products viability.

Smart systems are by the way called upon to play an important role in the clinical testing process as future smart fluidic systems and in-vitro testing platform should be able to modelise and simulate in the lab human's reactions to new drugs for instance. This should therefore contribute to quicker and less costs intensive clinical trials, a major barrier in the development of new drugs

5.2 Manufacturing

In the field of manufacturing, robotic co-workers that can work with, or in the presence of humans are an important application domain for specific smart systems functionalities including environment recognition and monitoring, Motion Control, Human Robot Collaboration.

Another significant area are smart process lines that can analyse variations in raw materials and rapidly change parameters based upon prior experience. They combine functionalities like the monitoring of body parameters, multiple-parameter sensing and adaptive capabilities. Furthermore human quality aspects (e.g. smell, taste) could be considered within smart process or production lines.

By using Smart Systems in the field of manufacturing technologies, quality assurance aspects will be strongly integrated into production processes. As a result the versatility, reliability, cost- and time efficiency will be enhanced.

Quality control on manufacturing and industrial inspection will be improved through computer vision systems that will help inspection procedures, analyzing defects in production lines and the validation and cataloguing of pieces or components. Computer vision systems provide quality control and real-time feedback for industrial processes, overcoming physical limitations and subjective judgment of humans. Automated systems capable of high-speed measurement of parts and flaws yield unprecedented quality.

5.3 Environment

In the environment field advanced smart systems for efficient use of resources such as water and light to create or maintain micro climates for agriculture can be considered applications with specific functionalities, as well as functionalised products to detect and allow specific treatment of recoverable materials, e.g. RFID-based.

5.4 Automotive

An exciting example of a Smart System from the automotive domain is the smart wheel which aims to integrate braking as well as suspension functions and active torque vectoring, thus offering additional features in vehicle stability. The specific functionalities it requires include Multi-Parameter Sensing, Motion Control, Power Control, Thermal Management, and Closed Loop Control.

Smart systems for automotive lighting include the opportunity for enhanced intelligent and safe illumination, car-to-infrastructure and car-to-car communication, as well as the generation of optical effects. These advanced automotive systems include spatial and frequency control of the actuated light elements, sensors for two-way communication, and excellent thermal management.

Of particular interest also is the highway pilot which enables highly automated driving without the driver in the loop, including autonomous overtaking, but allowing the driver to intervene. This requires a sophisticated combination of functionalities like e.g. Environment Recognition, Data Fusion, Positioning/Mapping, and Monitoring of Body Parameters.

Further applications such as lane-departure warning and self-parking will be among the major growth drivers of the market for machine vision.

Machine vision can improve automotive safety and convenience features in a number of ways, playing a key role in applications like lane departure warnings, collision mitigation, self-parking and blind-spot notifications, providing new tools for automated driving.

Machine vision allows machines to understand their environment through visual means. While image sensors have been around for a long time, such sensors are unable to “see” without the aid of advanced processors in order to interpret an image. It is the combination of sensing and interpreting images, and the availability of powerful, low-cost processors, that has made possible to incorporate vision capabilities into a wide range of smart systems.

In automotive vision systems, one of the established markets for machine vision, the trend is shifting from multiple small markets for miniaturized solutions towards a growing market for integrated intelligence, and is also heading for new applications enabled with even greater intelligence. While an older applications model could be found to feature many systems and cameras possessing a variety of individual performance needs and solutions, an integrated vision system boasts of multi-core and high-performance systems, with fewer cameras but more complex and cohesive solutions.

Machine vision is also used in a variety of industrial security applications, another powerful growth driver for the field.

In factory automation, for instance, applications for this established market can be found in smart vision sensors, machine vision cameras and compact vision systems. As many as 6.1 million units of machine vision hardware could be possible by 2016, up from 3.3 million units in 2011.

5.5 Energy

In the area of energy, smart systems are being developed for alternative energy generation, reduction of energy consumption, and the management of the balance between energy-generating and energy-consuming systems. The intelligence that is being added to our photovoltaic and wind systems, to our heating, ventilation, lighting and airconditioning systems, and to educate users about power consumption and generation, will change how we think about and use energy. We will introduce systems that integrate objective feedback (such as temperature, glare or windspeed) with user preferences to balance the needs of the smart grid with the user's wellbeing and comfort. Furthermore, the effect of demand/response to aid grid stabilization while taking into account facilities and city managers' needs will mean a level of automated intelligence at the local, district, building and citywide level.

6 Technology Base

The key to the functionality of any smart system is the unique combination of its components; neither integrated circuits nor sensors or actuators alone would be able to address the tasks that the system carries out. Often, the form factor of the smart system, its functionality or the environmental conditions it operates under will impose strict demands on the materials and components that are being used to engineer it. These constraints may require revisiting existing technologies, or even additional fundamental studies. As explained in this section, therefore, research and development in smart systems generally extends across a wide range of technology readiness levels. Moreover, the future development of smart systems will require improvements and innovations in multiple technology fields.

Smart systems generally carry out some form of data and signal processing, which may be performed by nanoelectronic circuits (based on CMOS or beyond-CMOS technologies), electronic circuits with novel form factors (e.g., large-area or flexible electronics), mixed-signal or analogue and high-frequency **electronics**. The management of electric energy flows requires power electronic components and circuits. Often, smart systems will not only process electrical signals but rather use **photonic, microoptical, microfluidic and micro-electromechanical components** in combination with electronics to achieve functionality.

To enable smart systems to interact with their environment, technologies for mechanical, electrical, optical, chemical, and biological **interfacing** and for the transfer of energy and data are required. Many applications require better human-machine interfaces. Furthermore, faster and more compact, energy efficient and fail-safe **communication systems** need to be developed, in particular wireless, near-field and RFID technologies. Moreover, robust concepts for physical, chemical, and biological **sensors and sensor systems** that are highly sensitive and selective and that possibly work at a distance and in a multitude of complex and/or harsh environments are essential for analytics. To increase their accuracy, these systems need to be capable of hardware or software based data fusion. Moreover, such sensors should operate with high energy efficiency and at low power to facilitate autonomy. Energy efficient mechanical, piezoelectric, electromagnetic, thermal, optical, and chemical **actuation and stimulation mechanisms** will enable smart systems to influence their environment. All of the above functionalities require innovations in structural, electronic, magnetic, piezoelectric, active, fluidic, biocompatible and other **materials**, which should be able to function under harsh operating conditions. Electronic systems will increasingly require wide band gap materials as well as electroactive polymers and metal organic compounds.

The evolution of smart systems towards higher autonomy relies on increasingly powerful **computational and mathematical methods** for signal processing, data analysis, data fusion, and data storage that need to take into account the interaction of the different sensors and microprocessors that are involved. Moreover, increasing autonomy and miniaturisation requires components for high-density **energy storage** as well as efficient, highly integrated and possibly modular solutions for electrical and thermal **energy management**. Energy generation and scavenging from motion, thermal gradients, electromagnetic fields, light, chemical reactions or biological processes can ensure reliable energy supply. On the system level, the highest state of evolution requires adaptation as well as self-testing and self-healing technologies.

As smart systems evolve, system engineers need to be able to handle increasing complexity. Short times to market will only be possible if engineers can use **methods and tools for automated design and rapid prototyping.** Multi-physics and multi-scale **models and simulations** need to be developed which enable the computational analysis of materials, energy flows, mechanical motion, microfluidic processes, chemical and biological processes, optical and photonic systems, electromagnetic fields and their interaction with one another. Depending on the application, these methods will have to enable steady-state as-well as time-dependent analyses. Owing to its interdisciplinary approach, smart systems development can benefit in particular from methods for co-design, which take into account components, products and processes alike. On a broader level, certification **standards** as well as design **rules** and testing and inspection methods that guarantee electromagnetic, chemical, thermal and mechanical functionality and robustness as well as minimal environmental impact through emissions and waste will facilitate joint progress across industries.

The production of smart systems relies on the further development of **technologies for component fabrication and system-level integration**. Smart systems necessarily combine multiple materials and technologies to deliver functionality. Spanning this breadth requires a broad range of product-led methods and processes, many of which are individually well-developed but not necessarily proven when combined to process integrated multi-material systems. On the component level, **processes** for top-down as well as bottom-up fabrication need to be developed further, e.g. lithography, chemical and physical etching, plasma and vapour deposition, electrochemical plating, surface functionalisation, atomic layer deposition, (3D-)printing and nanoimprinting, micromachining, forming and handling. System integration in-package, on-chip, on-surface, on-tag, in-fabric, or on-PCB requires **methods and materials** (metals, ceramics, polymers etc.) for assembly, bonding, welding, gluing, brazing and soldering, moulding and micromoulding and encapsulation. These materials systems need to adapt to diverse and possibly harsh operating conditions, and they need to ensure the functionality of the smart system that is associated with its, e.g., optical or electromagnetic, interfaces. The cost-effective production of smart systems will require advanced **manufacturing equipment** and new methods to embed such systems in, for example, garments or robots.

The diversity of the base technologies that are involved in engineering smart systems can best be illustrated using the examples that have already been introduced in part 3.3 of this document:

Consider the 1st generation smart system discussed earlier, a gyro mouse that detects hand movements and allows the user to control the position of an on-screen cursor. This device requires a sensor that detects horizontal and vertical movements, as well as suitable signal processing electronics to derive the movement in x- and y-direction from the physical response of this sensor. To transmit these data to a PC, the mouse also needs to contain a transmitter, a receiver and electronics for wireless communication. Finally, components for energy storage and management are required. The 2nd generation smart system is even more complex. This continuous glucose monitoring system for patients with diabetes measures subcutaneous fluid parameters to predict blood sugar trends and warn the user to take action. In terms of base technologies, such a system will require sensor elements to detect glucose levels in the patient’s tissue, low-noise and low-power signal processing components to acquire and digitize the data coming from these sensors, and microprocessors to analyze the data and make decisions on future trends and possible warnings. To maximize usability and autonomy, all these electronic components should be highly energy efficient. By the same token, the glucose monitoring system requires innovations in battery technology and energy scavenging to ensure long-lasting energy supplies. Since the monitoring system needs to be wearable, it should also be made compact and lightweight. To allow the patient to read out and store their glucose data on other devices, wireless communication systems should be integrated. Finally, when designing such a glucose monitoring system, engineers need to consider the interplay of its individual components and ensure electromagnetic compatibility to prevent faulty readouts. The development of the 3rd generation smart system discussed earlier, a fully automated car, will require innovations in almost all of the technology fields outlined above.

7 Implementation in JTI ECSEL

In preparation of the Multi Annual Strategic Plan of the JTI ECSEL and summarizing the discussion of the previous chapters, expectations from EPoSS, a timeline for the implementation of smart systems topics and potential synergies of the cooperation with ENIAC and ARTEMIS are stated from the perspective of EPoSS in this last chapter.

7.1 EPoSS expectations from and contributions to the JTI ECSEL

The EPoSS community fully acknowledges that all three platforms involved in the JTI ECSEL are driven by the objective of Horizon 2020 to bridge the gap between research and innovation, and are thus aiming at applications in products or services for the good of society, economy and environment in Europe (see chapter 1). At the same time, EPoSS members emphasize specific applications that are enabled by smart functionalities (see chapters 3, 4 and 5), and they point out that a multitude of particular base technologies have to be developed in integrated at various TRL in order to provide these functionalities (chapter 6). By this specific approach EPoSS on the one hand complements the other two platforms with base technologies, integration concepts and smart functionalities that they don't cover, and on the other hand, it also overlaps with them in those cases where their base technologies are needed for a specific smart functionality. Therefore, the EPoSS community is convinced that the cooperation of the three platforms will mutually enrich their activities in the JTI ECSEL, and lead to synergies particularly in those application fields that are built on functionalities requiring the specific technology bases of two or even all three of them (see Figure).

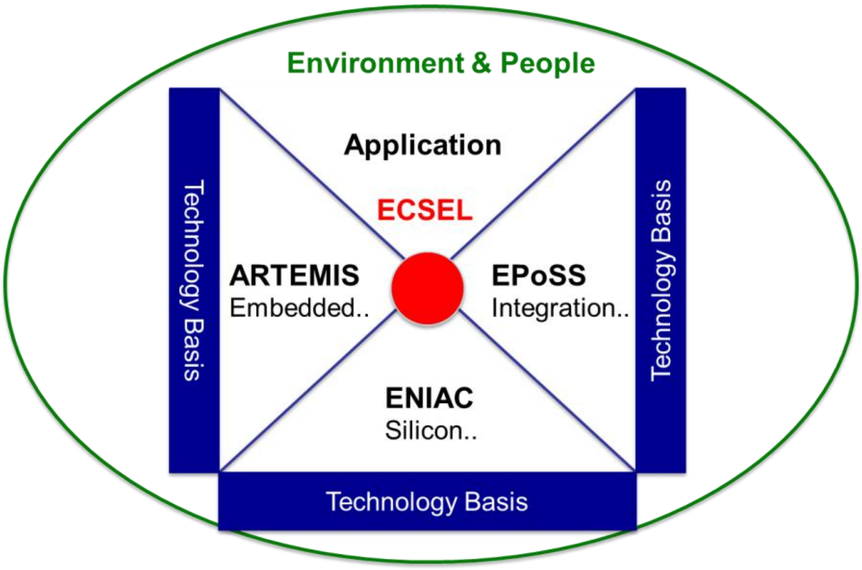

Figure: Potential Synergies of the collaboration in the JTI ECSEL.

7.2 Topics for potential joint projects

Based on the consideration outlined above, the EPoSS community is convinced that besides the specific priorities that the three platforms will emphasize according to the roadmaps, some topics for joint projects can be identified for the Multiannual Strategic Plan. Examples include autonomous and communicating vehicles (EPoSS part: sensing, actuation and texting), plug-in capabilities for cars (EPoSS part: data fusion), analytical instruments (EPoSS part: system integration), characterisation, monitoring and reduction of energy consumption and environmental impacts (EPoSS part: sensor fusion and integration in harsh environments), appliances for smart homes (EPoSS part: human machine interfaces).

8 RIAPs 2014-2020 on Smart Systems Integration JTI ECSEL

This chapter summarizes the part on Smart Systems in the Multi-Annual Strategic Research and Innovation Agenda (MASRIA) of the JTI ECSEL which is the basis document for the Research and Innovation Annual Plans (RIAPs) and thus the calls for proposals on Smart Systems Integration in 2014-2020. It is based on an intense consultation process within the membership of the EPoSS Association, and was discussed with the broader Smart Systems Integration stakeholder community at a Strategy and Brokerage Event on 3 February 2014 in Brussels.

8.1 EPoSS Strategy Summary

- **Smart Systems Integration**
  Smart Systems are self-sufficient intelligent technical (sub-)systems with advanced functionality that provide solutions to address grand challenges and risks for mankind in social, economic and environmental terms. They sense, diagnose, describe, qualify and manage a given situation in order to perceive complex circumstances, be predictive, and take autonomous decisions. Their operation is further enhanced by their ability to mutually address, identify and work in consort with each other. They are able to interface, interact and communicate with users, their environment and with other Smart Systems, and to manage their energy consumption. Smart Systems can be standalone, networked, or embedded into larger systems; they comprise heterogeneous devices combining data processing with sensing, actuating, energy scavenging, and communication and they excel in self-reliance and adaptability. What distinguishes smart systems from systems which are purely reactive is the knowledge base.

- **Strategic Research Driven by Products and Applications**
  Smart Systems Integration is a key enabling technology that bridges the gap between components and products. It thus guarantees the world market success of European technology companies in numerous and different application fields. The connection between Smart Systems and the application sectors that they serve has been emphasized in the Strategic Research Agenda (SRA) of the European Technology Platform on Smart Systems Integration (EPoSS). The first EPoSS SRA published in 2007, and any updates since were structured according to key application sectors for Smart Systems Integration: transport and mobility health, manufacturing and factory automation, communications, energy, aerospace and environment. Roadmaps for medium and long-term research needs are provided not only in terms of technologies and functionalities, but also in terms of applications and markets. The research priorities derived from these roadmaps have influenced the work programmes of the European Commission's Seventh Framework Programme for Research (FP7) including the Public Private Partnerships (PPP), and have been implemented by a multitude of successful research projects with a total funding in the order of 2.7 billon EUR.

- **Systems Development Focused on Functionalities**
  Smart Systems developments are ultimately driven by the application to user-level needs of individuals and society. They identify the key systems functionalities in the domains of sensing and actuation, interfaces, signal and cognitive processing, energy management and scavenging, communication and networking, and knowledge base to address those needs, some of which are general whereas others are specific for a particular application, and they marshal the most appropriate technologies in combinations to enable those functionalities. The progressive development of Smart Systems is characterised by their increasing autonomy through the twin effects of becoming increasingly self-sufficient in energy requirements and becoming less reliant upon external supervision and control. Advancements in the „smartness" of a system are determined by the degree to which the key functionalities are implemented. The EPoSS community has defined the evolution of smart systems as follows: 1st Generation Smart Systems integrate sensing and or actuation as well as signal processing to enable actions, 2nd Generation Smart Systems are built on multifunctional perception, are predictive and adaptive, and 3rd Generation

Smart Systems perform human-like perception and action and generate energy. These generations of smart systems develop at different speed depending on the functionality considered.

- **Research and Innovation on Enabling Technologies**
  The implementation of key functionalities of Smart Systems requires the integration of inter-disciplinary knowledge from a manifold of enabling principles including nanoelectronics, micro-electro-mechanics, biosystems technologies, magnetism, photo-nics, chemistry, radiation and a multitude of other physical or chemical principles. Optimized combinations of building blocks for data processing with sensing, actuating, energy scavenging, and communication enable smart systems to interface, interact and communicate with users, their environment and with other Smart Systems, and to manage their energy consumption. Often, the form factor of the smart system, its functionality or the environmental conditions it operates in impose strict requirements on the materials and components that are being used to engineer it. These constraints require research and development in smart systems to extend across a wide range of technology readiness levels.

8.2 EPoSS Priority Topics for ECSEI

The future development of smart systems requires improvements and innovations in the following technology domains:

- Smart systems generally carry out some form of data and signal processing, which may be performed by nanoelectronic circuits (based on CMOS or beyond-CMOS technologies), electronic circuits with novel form factors (e.g., large-area or flexible electronics), mixed-signal or analogue and high-frequency **electronics**. The management of electric energy flows requires power electronic components and circuits. Often, smart systems will not only process electrical signals but rather use **photonic, microoptical, microfluidic and micro-electromechanical components** in combination with electronics to achieve functionality.

- To enable smart systems to interact with their environment, technologies for mechanical, electrical, optical, chemical, and biological **interfacing** and for the transfer of energy and data are required. Many applications require better human-machine interfaces. Furthermore, faster and more compact, energy efficient and fail-safe **communication systems** need to be developed, in particular wireless, near-field and RFID technologies. Moreover, robust concepts for physical, chemical, and biological **sensors and sensor systems** that are highly sensitive and selective and that possibly work at a distance and in a multitude of complex and/or harsh environments are essential for analytics. To increase their accuracy, these systems need to be capable of hardware or software based data fusion. Moreover, such sensors should operate with high energy efficiency and at low power to facilitate autonomy. Energy efficient mechanical, piezoelectric, electromagnetic, thermal, optical, and chemical **actuation and stimulation mechanisms** will enable smart systems to influence their environment. All of the above functionalities require innovations in structural, electronic, magnetic, piezoelectric, active, fluidic, biocompatible and other **materials**, which should be able to function under harsh operating conditions. Electronic systems will increasingly require wide band gap materials as well as electroactive polymers and metal organic compounds.

- The evolution of smart systems towards higher autonomy relies on increasingly powerful **computational and mathematical methods** for signal processing, data analysis, data fusion, and data storage that need to take into account the interaction of the different sensors and microprocessors that are involved. Moreover, increasing autonomy and miniaturisation requires components for high-density **energy storage** as well as efficient, highly integrated and possibly modular solutions for electrical and thermal **energy management**. Energy generation and scavenging from motion, thermal gradients, electromagnetic fields, light, chemical reactions or biological processes can ensure reliable energy supply. On the system level, the highest state of evolution requires adaptation as well as self-testing and self-healing technologies.

- As smart systems evolve, system engineers need to be able to handle increasing complexity. Short times to market will only be possible if engineers can use **methods and tools for automated design and rapid prototyping.** Multi-physics and multi-scale **models and simulations** need to be developed which enable the computational analysis of materials, energy flows, mechanical motion, microfluidic processes, chemical and biological processes, optical and photonic systems, electromagnetic fields and their interaction with one another. Depending on the application, these methods will have to enable steady-state as-well as time-dependent analyses. Owing to its interdisciplinary approach, smart systems development can benefit in particular from methods for co-design, which take into account components, products and processes alike. On a broader level, certification **standards** as well as design **rules** and testing and inspection methods that guarantee electromagnetic, chemical, thermal and mechanical functionality and robustness as well as minimal environmental impact through emissions and waste will facilitate joint progress across industries.
- The production of smart systems relies on the further development of **technologies for component fabrication and system-level integration**. Smart systems necessarily combine multiple materials and technologies to deliver functionality. Spanning this breadth requires a broad range of product-led methods and processes, many of which are individually well-developed but not necessarily proven when combined to process integrated multi-material systems. On the component level, **processes** for top-down as well as bottom-up fabrication need to be developed further, e.g. lithography, chemical and physical etching, plasma and vapour deposition, electrochemical plating, surface functionalisation, atomic layer deposition, (3D-)printing and nanoimprinting, micromachining, forming and handling. System integration in-package, on-chip, on-surface, on-tag, in-fabric, or on-PCB requires **methods and materials** (metals, ceramics, polymers etc.) for assembly, bonding, welding, gluing, brazing and soldering, moulding and micromoulding and encapsulation. These materials systems need to adapt to diverse and possibly harsh operating conditions, and they need to ensure the functionality of the smart system that is associated with its, e.g., optical or electromagnetic, interfaces. The cost-effective production of smart systems will require advanced **manufacturing equipment** and new methods to embed such systems in, for example, garments or robots.

8.3 Timeline of Implementation of Priority Topics in ECSEL RIAPs 2014-20

Year	Technologies	Functionalities	Applications
2014	**Building blocks for the integration and interaction of smart systems with their environment:** sensors and sensor systems, (power) electronics, actuators, wireless communication systems as well as materials and methods for physical integration ensuring reliability and robustness	Gen 1/2 sensing and actuation, communication and networking	power train control for EVs, environment recognition for robots, body area networks for health monitoring
2015	**Components and integration concepts for smart energy and thermal management:** control, storage, transfer, generation, harvesting of energy, and supporting communication solutions	Gen 1/2 energy management and scavenging, communication and networking	battery management, smart grids, renewable energy sources
2016	**Solutions and methods for automation and operation of smart systems in**	Gen 2 and partly 3 signal and cognitive	automated vehicles and manufacturing

	complex environments: sensor fusion, cognitive cooperation, robust and reliable materials and components, physics of failure	processing, Gen 1/2 interfaces	processes, environment recognition
2017	**Integration methods and interfaces for smart systems operating under harsh and complex conditions:** compatibility with organic, chemical, biological, neural systems	Gen 2/3 interfaces	neuro plug, micro needles, artificial organs, smart fluids, environ-mental monitor-ing
2018	**Advanced smart systems for autonomous operation** based on building blocks linked to knowledge base	Gen 3 sensing and actuation, communication and networking, Gen 2 signal and cognitive processing, knowledge base	autonomous transportation systems, artificial organs, robots
2019	**Smart systems for complete user interaction** matching requirements of augmented reality, data fusion	all of the above as well as Gen 3 interfaces	prosthetics, implants, artificial eyes, human-machine interfaces
2020	**Breakthroughs in reduction of impact of smart systems** on materials use, waste production, energy consumption, and cost; self-healing capabilities	Gen 3 of all functionalities	visionary products in transportation, health etc.

In addition to the priority topics, basic technologies and methods for design, simulation, fabrication, physical integration, prototyping, testing, reliability and security as well as innovations in materials remain priorities for the entire duration of Horizon 2020.

8.4 Possible Call Topics 2014

Smart Systems Integration

Optimized combinations of building blocks for data processing with sensing, actuating, energy scavenging, and communication enable smart systems to interface, interact and communicate with users, their environment and with other smart systems, and to manage their energy consumption. Often, the demands on the form factor of the smart system, its functionality or the environmental conditions it operates in impose strict requirements on the materials and components that are being used to engineer it. These constraints call for research and development across a wide range of technology readiness levels and improvements and innovations in multiple technology fields

For developing those critical functionalities in smart systems for mature products and applications, particularly in the transportation and health domains, the building blocks for interaction with the environment, the required advanced materials and the methods of physical integration need to be further improved and adapted. Therefore, the focus of the smart systems call of the JTI ECSEL in 2014 is on advanced research and innovations in the following technology fields

- Micro-electromechanical and other physical, chemical, and biological **sensors and sensor systems** that are highly sensitive and selective for critical parameters as well as reliable in a multitude of environments like, e.g. hazardous emissions, energy flows, road traffic conditions, manufacturing quality, and body fluids, and that possibly work remotely, are highly energy efficient and increasing autonomy. The combination of such sensors in multifunctional sensor networks or sensor swarms shall be particularly emphasized, and supported by dynamic, adaptive and cognitive data processing. To increase accuracy and address the superposition of signals, hardware based data fusion shall be achieved where possible.

- **Power electronic inverters and converters** and other, e.g. mechanical, piezoelectric, electromagnetic, thermal, optical, and chemical **actuators** that enable smart systems to influence their environment. A particular focus shall be on modular and highly integrated schemes of power control and actuation e.g. in traction motors that enable customized applications, low form factors, functional monitoring and cost reductions. Furthermore, advanced solutions for energy and thermal management, energy efficiency and energy harvesting / scavenging shall be implemented.
- Fast, compact, energy efficient, fail-safe and secure **wireless communication systems** for energy and data, particularly near field, RFID and visual technologies that assist smart systems in navigating the environment, interacting with infrastructures and with automatic geo location, both outdoors and indoors. Plug- and play solutions for the integration into the Internet of Things are of special interest, and data security should be taken care of.
- **Materials** for smart systems. This includes structural, electronic, magnetic, piezoelectric, active, fluidic, biocompatible and other materials meeting harsh operating conditions like e.g. heat, moist, radiation or harsh environments like e.g. combustion chambers, in vivo magnetic resonance, light extraction, high power density. Particular focus is on wide band gap materials for power conversion as well as on electroactive polymers and metal organic compounds for flexible substrates.
- **Methods** for the **physical integration** of smart systems in a multitude of environments ensuring reliability and robustness, e.g. in packages, on chips, in surfaces, inside printed circuit boards, on tags and in fabrics. This includes system level technologies like e.g. connecting, bonding, welding, gluing, brazing and soldering, moulding and micromoulding and encapsulation, and is strongly interlinked with the materials, e.g. SiC and GaN for power electronics devices, the fabrication processes, whether top-down lithography and etching or bottom-up 3D printing. Furthermore functional safety and EMC/EMI as well as self-diagnosis capabilities should be achieved, and the transfer of technologies between different applications fields should be exploited.

These technologies will provide key functionalities for smart systems of the 1st generation with most advanced sensing and actuating capabilities as well as innovative 2nd generation systems that are built on multifunctional perception and able to match requirements of critical environment, equipped with networking facilities and advanced energy scavenging and management capabilities.

Research, development, testing and prototyping in these technology fields can thus be expected to lead to a multitude of new products in various fields that are crucial for the competitiveness of European industry including innovative SMEs. Moreover, products exceling in the described functionalities provided by smart systems will greatly support the tackling of societal and environmental challenges. Examples include: power train control and wireless charging systems for electric vehicles, controlled combustion processes in conventional cars, surround sensing and vehicle communication systems for intelligent and automated automobiles, perception, navigation and mapping solutions for industrial robots, connected and intelligent data and power systems in smart buildings and cities, actively powered prosthetics, implantable devices for (preventive) diagnosis and monitoring, body area networks and other systems helping individuals to manage their health and wellness, e.g. chronic diseases by providing physiological/ hemodynamic data in a seamless manner, as well as solutions for microfluidic diagnostics in both health and non-health applications like e.g. environmental monitoring.

Project Types and Budgets:

Two types of projects are foreseen:

- Focused technical research and development projects of TRL between 2 (technology concept formulated) and 6 (demonstration in a relevant environment) and total budgets of more than 6 million Euros.
- Large scale innovation projects of TRL between 4 (technology validation in the lab) and 8 (system complete and qualified) and total budgets of more than 10 million Euros.

9 Annex: Strategic Research Agenda of EPoSS

STRATEGIC RESEARCH AGENDA

OF

EPoSS - THE EUROPEAN TECHNOLOGY PLATFORM ON SMART SYSTEMS INTEGRATION

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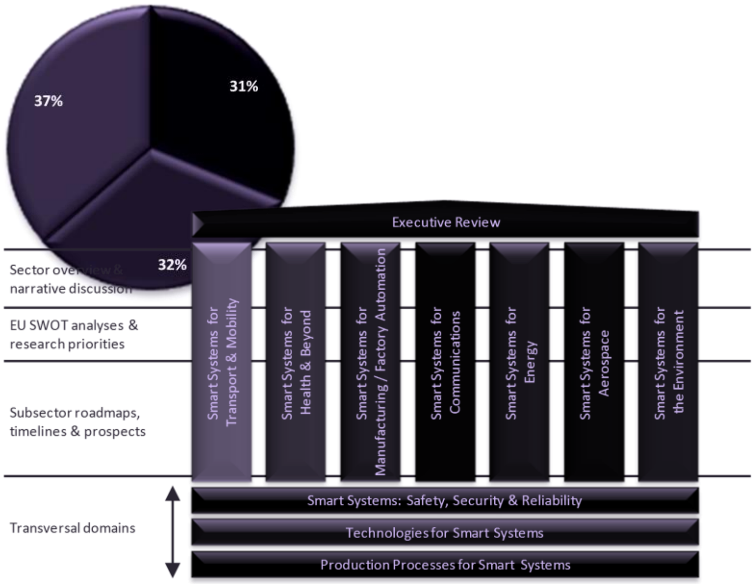
Foreword

(To be provided)

EXECUTIVE REVIEW



Executive Review

Introduction

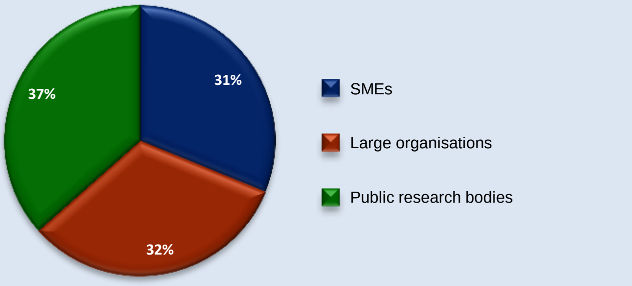
This Strategic Research Agenda looks towards 2020+ based upon expert information contributed by the members of EPoSS, the European Technology Platform on Smart Systems Integration, and its outreach to a wider community, including users and potential users of Smart Systems.

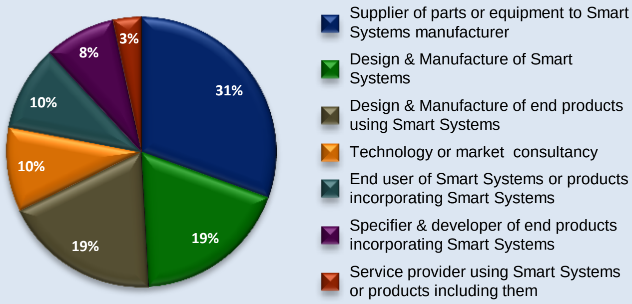
- It describes the current status and future prospects for Smart Systems in terms of technologies and markets in 32 subsectors within 7 applications sectors, and 3 further transversal domains that underpin the development, production and use of Smart Systems.
- It forecasts the introduction of progressive classes of Smart Systems across all of the subsectors.
- It analyses the European strengths, weaknesses, opportunities and threats regarding Smart Systems across each sector and transversal domain, and as a result puts forward research priorities.
- Its structure recognises the inextricable connection between Smart Systems and the application sectors that they serve. This is a striking distinction between this Strategic Research Agenda and those that are purely technology-driven.

The methodology employed, broad survey followed by expert discussion workshops, has released this document from the opinions of just a few: It is real data distilled from the insight of a whole community.

Methodology

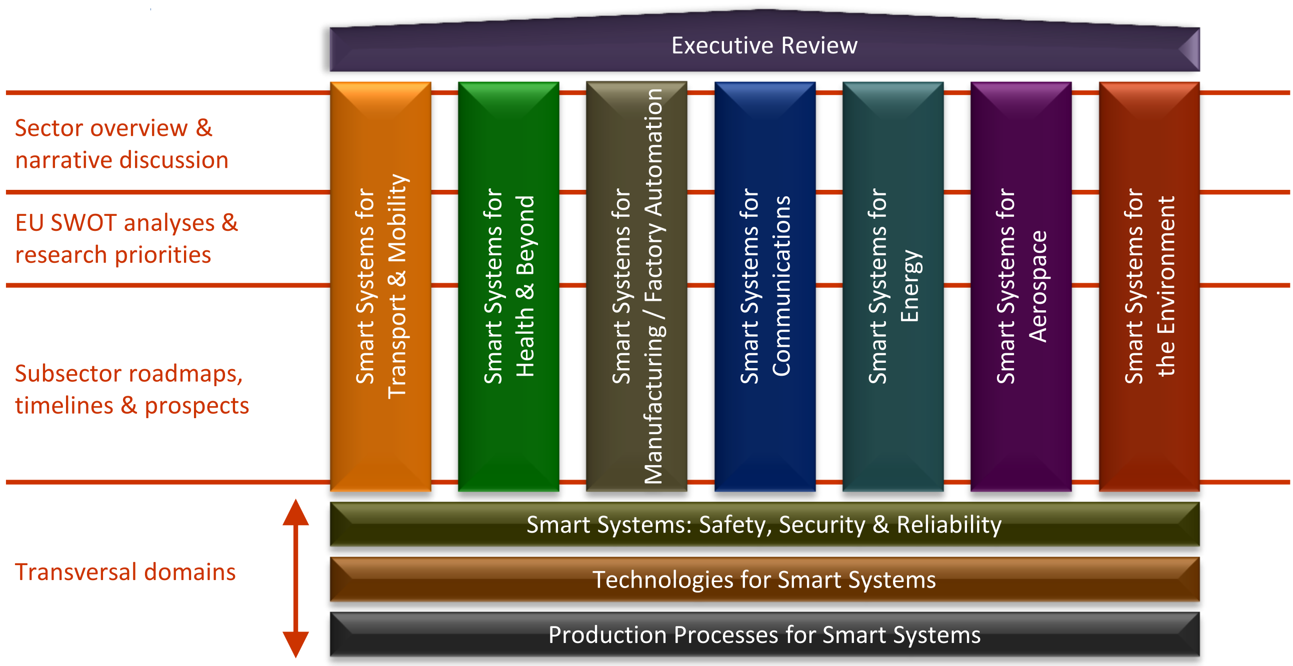
1. The IRISS structured survey of 93 contributors:





2. Stakeholder workshop for data validation and condensation.
3. Ten structured expert discussion workshops seeded by the data from Step 2.
4. Outcomes from expert workshops prepared by specialist chapter editors.

Structure of the Strategic Research Agenda



Visions of Smart Systems

Photograph: *Frog Design*

Frog Design envisage smart face masks that protect but also sample pollution – communicating city-wide with other masks to provide a map of air quality

rapyuta.org – *Bart Van Overbeeke Fotografie*

Where robots Google - the Rapyuta database is part of the European Robo Earth project, sharing and standardising the way robots perceive the human world

Photograph : *United States Coast Guard*

Autonomous drones – gaining wide access to US airspace by 2015, and 30,000 flying worldwide by 2020 – will be a huge driver for light, efficient, Smart Systems development

Smart Systems not only unite multiple technologies, they are strongly tailored to application sectors. This knowledge-rich environment is fertile ground for a truly European manufacturing supply chain, and its involvement of agile, innovative, SMEs.

All forms of *Transport & Mobility* and their necessary infrastructure are continually demanding increasing levels of safety, efficiency and environmental performance. Smart Systems offer reduced operator distraction and error, and optimisation of vehicle control, navigation and logistics.

In *Healthcare*, Smart Systems promise benefits across the whole spectrum of healthcare and wellbeing, from personal diagnosis and monitoring, through treatment and the preparation of targeted drugs and implants, and ultimately to enhanced levels of telemedicine and personalised health systems across the community.

Smart Systems in *Manufacturing* promise to carry out local optimisation underpinned by local Knowledge Bases, ranging from the examination of raw materials and parts and predicting subsequent machine settings to compensate for variation, all the way through to optimising manufacturing parameters based upon end-product performance.

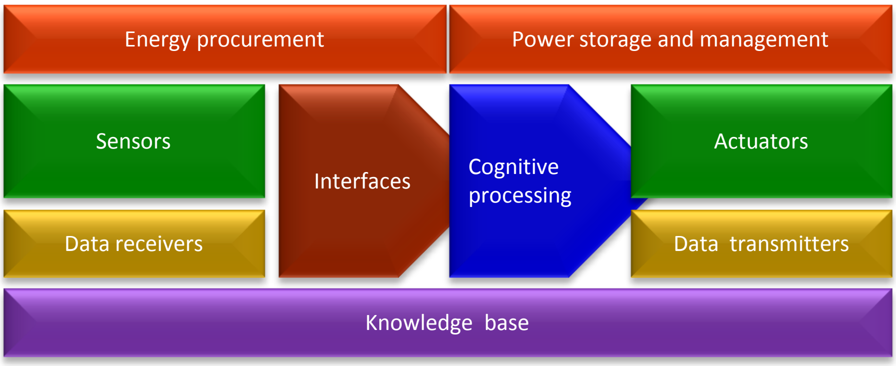
The capability for Smart Systems to *Communicate*, with users with other collaborating systems and within smart systems themselves is paramount. Smart Systems are set to enable immense strides in the whole domain of Communications within a Connected World.

Energy is behind almost every class of human endeavour. Civilisation depends upon care, security and efficiency at every stage from the discovery and unlocking of energy sources, through the storage and distribution of energy and on to its final use. Smart Systems, either autonomously or through networking, can safeguard and optimise every aspect of this critical chain.

The demands for precision, low mass, energy efficiency and utmost reliability make *Aerospace* a fundamental driver for high technology developments. Smart Systems bring the potential for the elimination of human error in control, guidance and navigation, and for the continuous monitoring of safety-critical structures and mechanisms.

Smart Systems, with their ability to accept multiple inputs and to infer appropriate responses, are already finding application in local *Environmental* controls. Their ability to network, coupled with small size and low cost, is expected to enable area-wide improvements not only in living and working environments, but also across the recycling and disposal landscape.

A Smart Systems primer



Smart Systems are self-sufficient intelligent technical systems or subsystems with advanced functionality, enabled by underlying micro- nano- and bio-systems and other components.

They are able to sense, diagnose, describe, qualify and manage a given situation, their operation being further enhanced by their ability to mutually address, identify and work in consort with each other.

They are highly reliable, often miniaturised, networked, predictive and energy autonomous.

- Smart Systems are autonomous or collaborative systems.
- They bring together sensing, actuation and informatics / communications to help users or other systems perform a role.
- By their very nature these systems combine functionalities.
- They may extract multiple functionalities from a common set of parts, materials, or structures.

Smartness

The concept of the Knowledge Base separates Smart Systems from systems which, although they may be automated, remain purely reactive.

As an example, the "automatic" camera of a decade ago would simply measure light intensity and adjust the shutter speed and lens aperture so that the photograph is properly exposed.

The typically "Smart" digital camera of today, by comparison, not only measures light intensity, but analyses the subject for signs of motion, for colour balance (including also the detection and optimisation of flesh tones), for facial expressions (smiles, closed eyes) and for contrast, to ensure that the focus is set for critical sharpness.

All these parameters are compared with a Knowledge Base inside the camera, which essentially distils the skills and experience of over 150 years of photography and applies it to the camera settings to produce a high quality image whilst being very simple to use.

Generations of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" in this case indicates increasing levels of "smartness" and autonomy, not that one generation seeds the next.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

For example: Personal alarms for emergency and falls are in wide use.

2nd generation Smart Systems are predictive and self-learning.

For example: The reliable, predictive detection of the possibility of a fall by a person at risk could trigger the visit of a carer before the event.

3rd generation Smart Systems simulate human perception/cognition.

For example: The remote real-time analysis of an active implanted neurological device could directly monitor and analyse a patient's brain function, through a Brain Computer Interface, for applications that extend far beyond healthcare.

Wireless Electro Encephalography - *Starlab*

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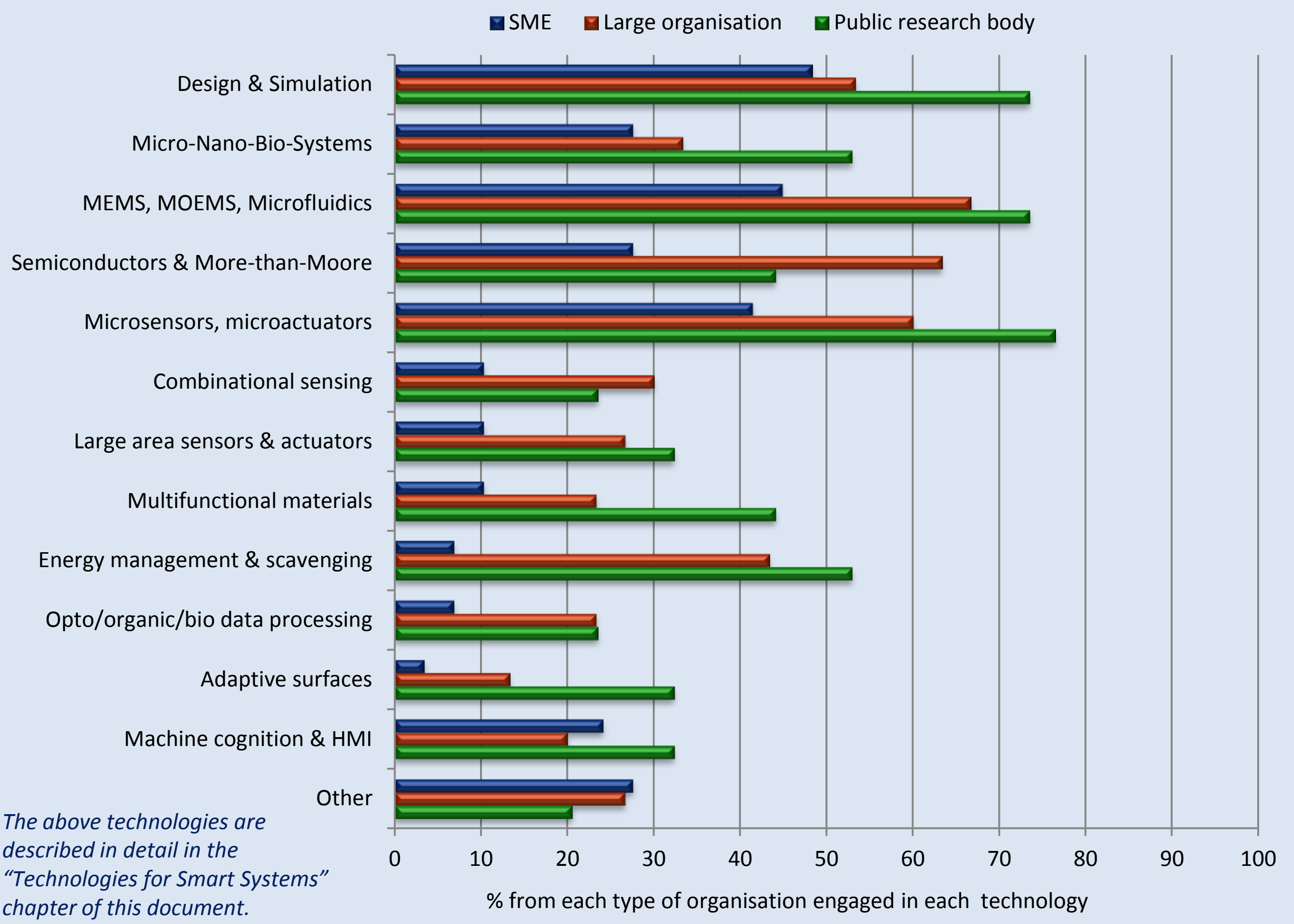
Underlying technologies

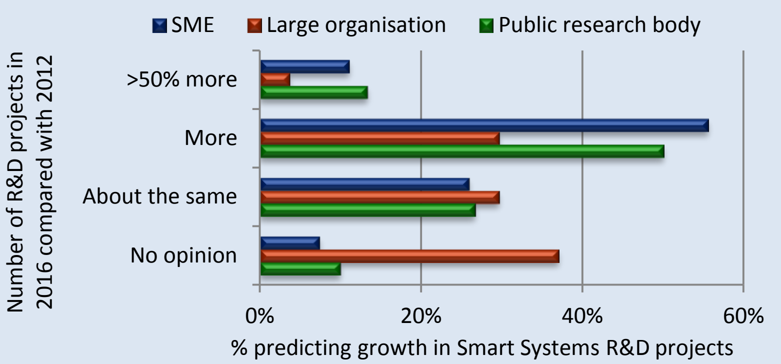
The IRISS survey of 93 contributors with activities in Smart Systems revealed a breadth of underlying technologies, the leaders being Microsensors & Microactuators; MEMS, MOEMS & Microfluidics; Design & Simulation; and Micro-Nano-Bio-Systems.

- Public research bodies tended to report engagement in a broad range of technologies, with a peak in Microsensing and Microactuation.
- Semiconductor & More-than-Moore technologies were reported as the province of Large companies.
- More than 20% of all organisations registered activity in "Other" technologies, which perhaps reveals new techniques on the horizon.



The above technologies are described in detail in the "Technologies for Smart Systems" chapter of this document.

Growth in Smart Systems R&D



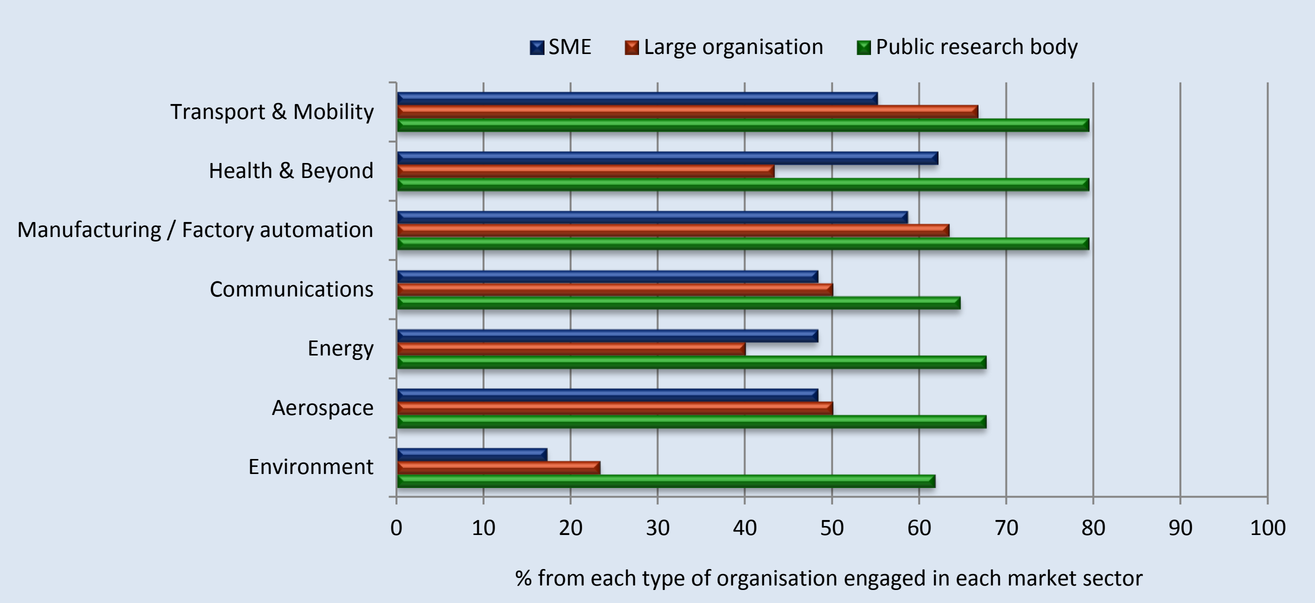
According to the IRISS survey, SMEs predominantly reported 1-5 Smart Systems R&D projects running in 2012, whereas Large companies and Public research bodies typically reported more than 10 projects, and in some cases more than 50.

Forecasts for R&D activity are tabled in the individual technology descriptions presented in the "*Technologies for Smart Systems"* chapter of this document, but the overall view illustrated to the left shows a majority of SMEs and Research Organisations forecasting increased Smart Systems R&D activity by 2016.

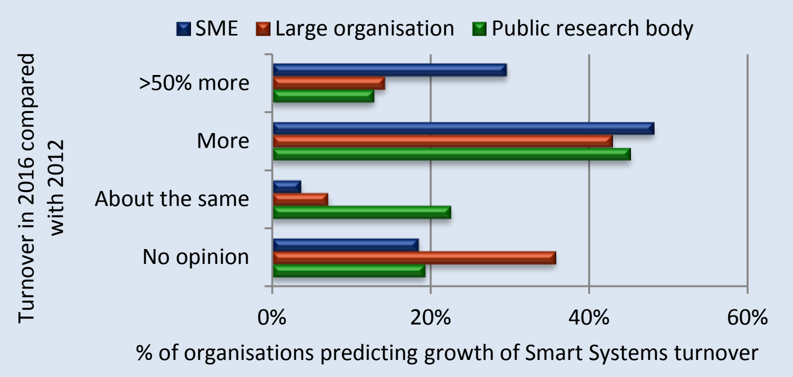
Market engagement

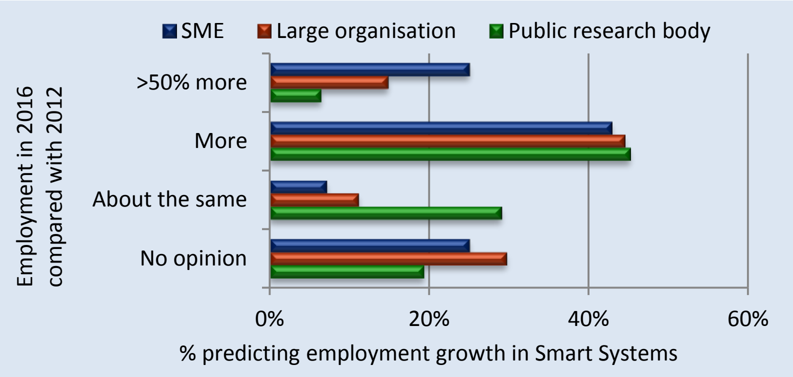
The IRISS 2012 survey of 93 contributors with activities in Smart Systems revealed sector-to-sector differences in the level of engagement reported by different classes of organisation.

- Public research bodies reported high engagement levels in each sector, with a possible interpretation being that basic research can support a wide variety of application.
- Large organisations show a clear lead over SMEs in the Transport & Mobility sector, whereas SMEs engage proportionally more in Healthcare.
- Relatively few commercial organisations reported engagement in the Environmental sector.



Corporate impact





The great majority of the organisations surveyed forecast sales growth in Smart Systems, with a significant proportion of companies, particularly SMEs, predicting turnover increasing by more than 50% over the 4-year period up to 2016 (illustrated left).

There were no predictions of reductions in sales, however an understandable proportion of organisations expressed no opinion, or uncertainty.

A similar picture emerged for growth in terms of employment, with a strong consensus for increases in manpower associated with Smart Systems.

Some caution is advised as the sample size, although useful to gain an overall picture, does not convey sufficient accuracy to draw detailed conclusions.

Sector growth prospects

It is easy to appear to be definitive about growth forecasts. It is far more difficult to properly substantiate views of the future, and in the case of Smart Systems it is even problematic to derive truly realistic figures for the present day.

The reasons for these uncertainties are:

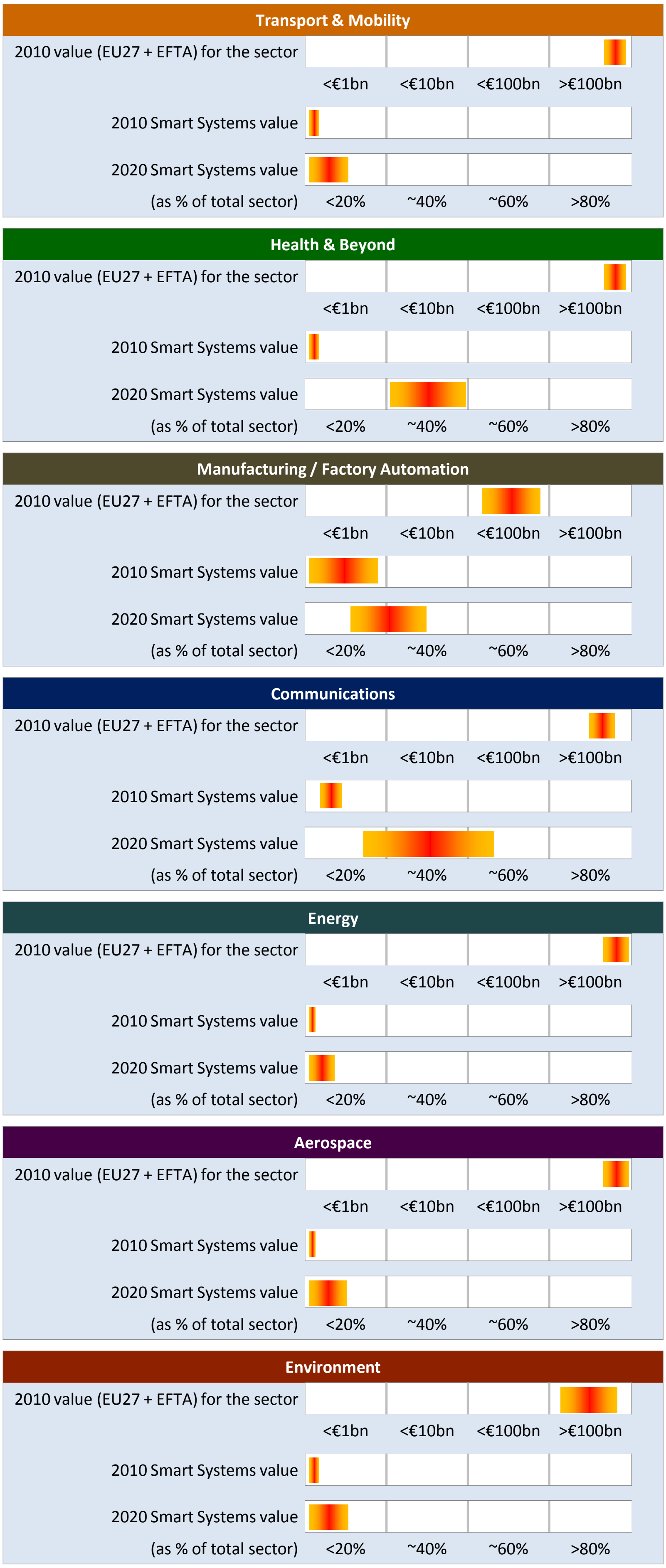
- Unlike standardised component parts, for which manufactured numbers, future demand and investments are predictable, Smart Systems are highly customised and made in smaller numbers, and thereby subject to strong fluctuations during relatively short commercial life cycles.
- Smart Systems are typically tied to specific applications sectors, for which the total value can only be estimated roughly, as, for example, there is no clear distinction between tangible product values and service values.
- It is difficult to discern the boundary between system and end product. It is easy, for example, to discover the total electronics value in an automobile, and to arrive at a figure for sensors and actuators, but it is tricky to identify the "smart" element of this total.

The charts to the right show the results of expert discussion groups, separately convened for each of the seven application sectors examined. Rather than arriving at financial figures, which, for the reasons tabled above would be inexact, and by virtue of being quoted in number form might convey an undue air of precision, each sector group agreed upon a graphic representation depicting the "form" of the current position and growth prospects in their sector.

It can be seen that:

- In all application sectors the proportion of value attributed to Smart Systems is expected to grow substantially.
- Even in those sectors showing Smart Systems as a relatively small proportion of value in 2010, that small proportion is of a very large whole.
- The Healthcare and Communications sectors predict the highest proportion of "smart" value in 2020.

The indicators in the charts are shaded to reflect uncertainty



Global challenges

Globalisation has drawn together a set of worldwide social, natural and economic effects, which concern every nation, company or entity. Accordingly, in addition to the specific Horizon 2020 challenges, the broader perspective must include global issues and major drivers such as:

- global healthcare
- demographic changes: urbanisation and ageing
- demand for fresh water
- food safety
- sustainable mobility
- environment and climate change
- conservation of scarce materials
- energy demand - efficient and secure access
- global convergence of information and communications technologies
- shifts in global employment patterns
- security strategies to reduce conflicts and terrorism

Feeding and sustaining progress

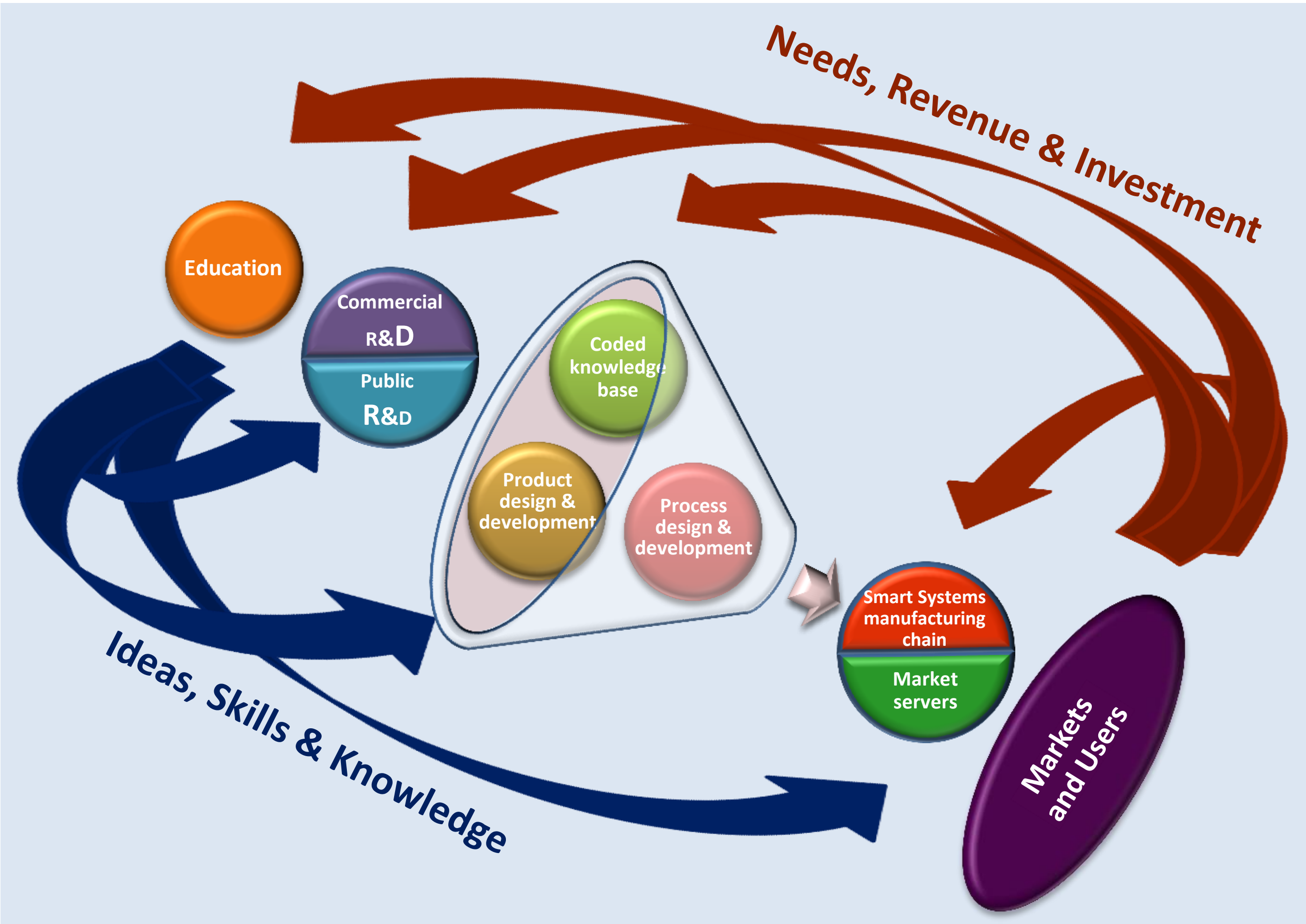
A business ecosystem may be defined as a sustaining environment to promote economic growth, skills growth, and growth in industrial capability and global competitiveness, fuelled by the extension of knowledge, the ambitions of innovators and the business and societal needs of the community at large.

Partial ecosystems relevant to this Research Agenda exist in the form of national and regional groupings of business and public research actors, special interest groups, knowledge transfer networks, research collaborations, and the tiered supply chains of major industrial players.

These groupings, although many of their members have relevant resources, do not explicitly recognise a focus upon Smart Systems, and are not yet marshalled to push EU capabilities in what is becoming a dominant and global industrial arena in the run-up to 2020.

A truly proactive ecosystem would accelerate the adoption and bring forward the rewards of Smart Systems.

A European ecosystem for Smart Systems



Roads to implementation

The aim of this Strategic Research Agenda is to provide a technology and market basis to guide the development of a rapidly expanding family of Smart Systems, based on multiple technologies, functions and materials, and to help establish a competitive European ecosystem for the design, research, development, advanced prototyping, manufacturing and commercialisation of these smaller, smarter (predictive, reactive and cognitive), network-integrated and energy autonomous systems.

The implementation of a European value chain, resistant to global competition, from technological know-how to innovative new solutions manufactured in Europe, will secure European industrial leadership in this domain and accelerate the application of Smart Systems to enhance the quality of life and to master Europe's upcoming societal challenges.

The primary objectives should include:

- The smart integration of nanoelectronics, micro-electro-mechanic, magnetic, photonic, micro-fluidic, acoustic, bio- and chemical principles, radiation and RF as well as completely new technologies into Smart Systems.
- The development of specific Smart Systems approaches across a diversity of application sectors and addressing societal challenges.

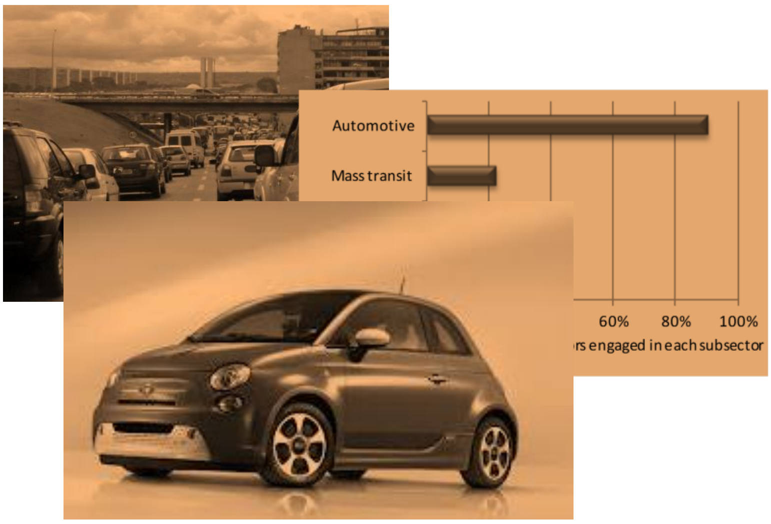
With a focus upon:

- Miniaturised systems based on high density integration, including heterogeneous materials, components or technologies as e.g. flexible/stretchable electronics, advanced packaging or biocompatible materials/surfaces.
- Smart Systems, engineered and enabled at the micro- or nano-scale that depend upon, contain or interact with biochemical processes, bio-materials or living organisms.
- Autonomous deployable Smart Systems that include efficient energy management (Zero Power Technologies) and energy harvesting from their operating environment.
- Smart Systems with multi-functional properties, based on micro-sensors and micro-actuators, in particular on next generation MEMS/NEMS with novel functionalities (MNBS, BioMEMS, MOEMS).
- Integrated Smart Systems, and smart systems networks, including sub-systems and components, able to communicate through wire-based or wireless links with a high-level of data integrity and self-monitoring, and self-testing functionalities.
- Tailored supporting activities to foster the establishment of a European Smart Systems ecosystem for the design, research, development, advanced prototyping, manufacturing and commercialisation of Smart Systems based on a European value chain.
- Realising the potential of innovative Smart Systems through the involvement of new players, especially creative, flexible SMEs and user groups, by facilitating cost effective access to European manufacturing capabilities and expertise.

Accordingly, these actions are put forward:

- Targeted actions for monitoring new technology and application trends and the influence of societal challenges and their changes, monitoring the implementation of roadmaps, and updating research agendas.
- Targeted actions for community building to foster the involvement of newcomers and first users, for monitoring the European ecosystem on Smart Systems Integration and its development, barriers, strategies, competitors and for applying the lessons learnt.
- The creation of specific fora for practitioners from non-engineering communities (e.g. surgeons, food technologists and police/security, who may be inexperienced in the use of Smart Systems) to engage directly with the Smart Systems Integration community to establish dialogues of user needs and supplier capabilities.
- Scaling up Erasmus Mundus to create a new class of "applications aware" multidisciplinary Smart Systems engineering teams.
- Evaluation of the technical capacity in the existing health, food, environment infrastructures for the installation of smart upgrades based on Smart Systems, and determine new strategies accordingly.
- The creation of a "Telemedicine in Europe Initiative" to augment the availability of medical expertise, sensitise and involve medical organisations, nurses, patients, relatives and decision makers.
- The evaluation of the tangible economic and societal values of the application of Smart Systems in the health, food, environment and security sectors to align with and support already strong legislation and active public interest.
- The provision of access especially for first time users of Smart Systems to information, education, design, pilot production and testing, with an emphasis upon exploiting the already available European capabilities.

SMART SYSTEMS FOR TRANSPORT & MOBILITY



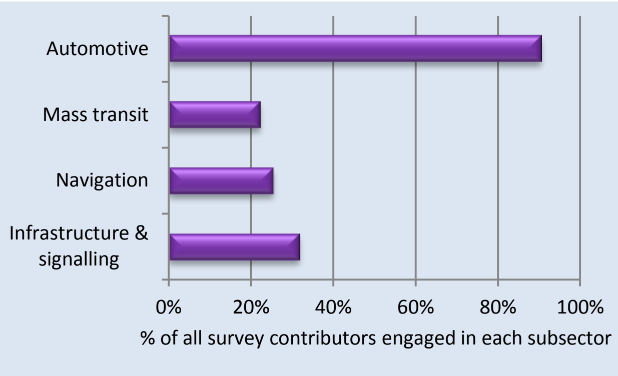
Smart Systems for Transport & Mobility

Overview

All forms of transport and their necessary infrastructure are continually demanding increasing levels of safety, efficiency and environmental performance.

Smart Systems, with their in-built knowledge base, offer reduced operator distraction and error, and optimisation of vehicle control, navigation and logistics potentially across multiple modes of transportation.

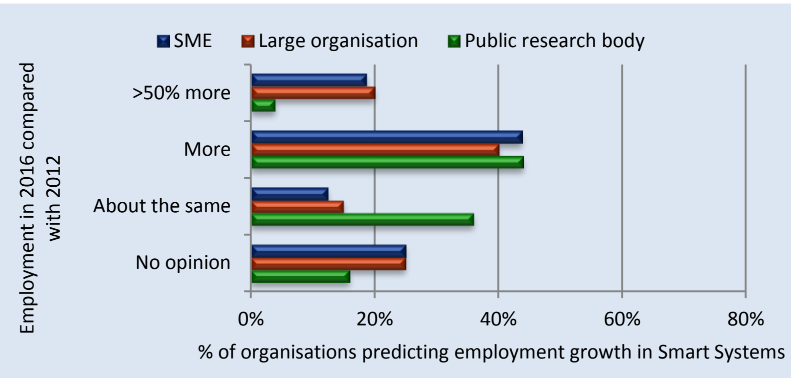
Fiat 500e - *Fiat*



Profile of subsectors

63 Smart Systems providers representing the Transport & Mobility supply chain from research through to market servers were predominantly engaged in the automotive sector (illustrated left).

Instruments as the EU Green Car Initiative have attracted the attention of Smart Systems providers and users. This activity needs to migrate to other aspects of transportation.



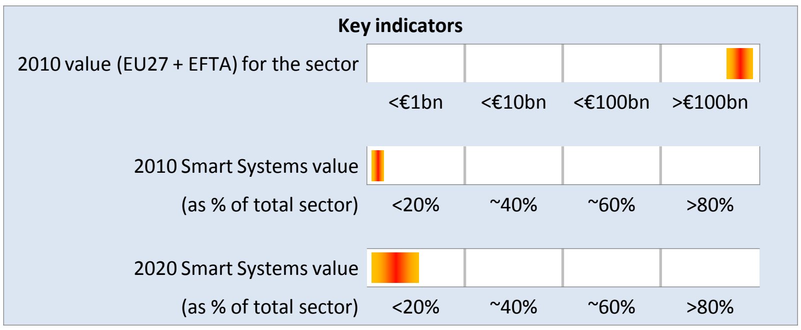
Growth prospects: Organisations

Of the Smart Systems providers surveyed, the great majority forecast employment growth, with a significant proportion of companies predicting headcount increasing by more than 50% by 2016 (illustrated left). There were no predictions of reductions in headcount.

A similar picture emerged for growth in financial terms.

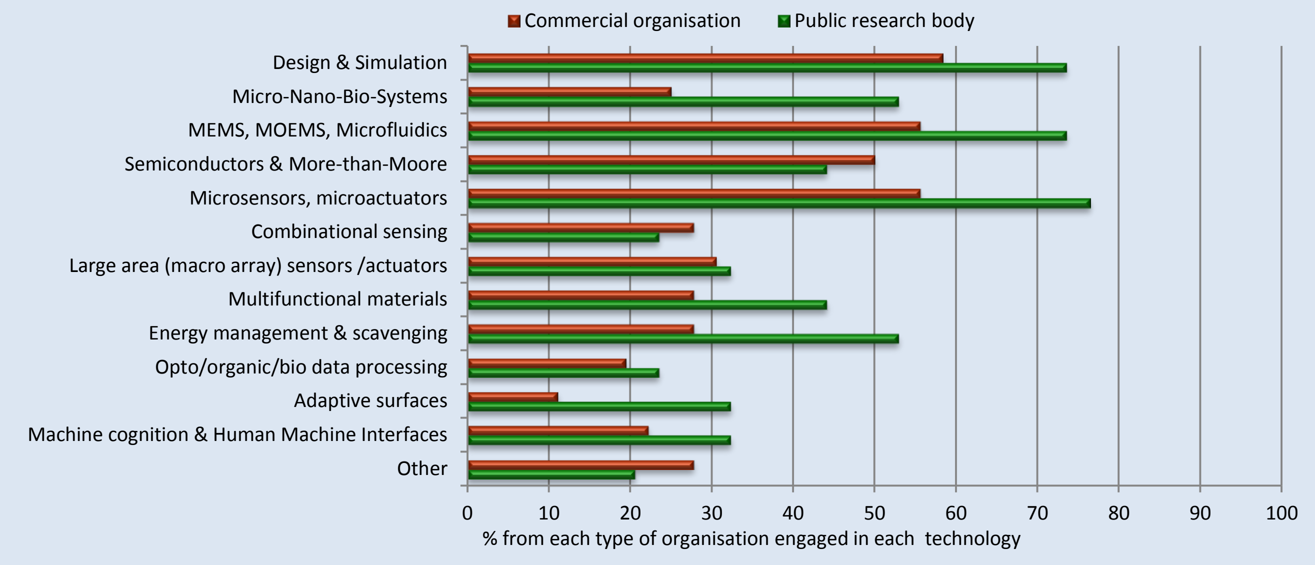
Growth prospects: Whole sector

The Transport sector in EU27 is immense in value (>€640bn). The sector represents ~22% of worldwide production and R&D investments are ~5% of turnover (>€26bn). Currently Smart Systems account for possibly ~1% of this, but could rise to ~10% (>€60bn€ by 2020 through the greater adoption of sensor networks in the automotive subsector, smart devices for navigation, and seamless multimode transportation.



The indicators above are shaded to reflect uncertainty

Underlying technologies



Four clear front-running technologies were reported by companies engaged in mobility & transportation, respectively: Design & Simulation, MEMS, MOEMS and Microfluidics, Microsensors & Microactuators, Semiconductors & More-than-Moore technologies.

Interestingly, companies engaged in this sector are far less engaged in Micro-Nano-Bio-System (MNBS) technology than the companies in four other sectors represented in this Strategic Research Agenda – Healthcare, Energy, Environmental and Manufacturing.

Following from the sector profile shown earlier in this section, support action should be considered to:

- Migrate the strengths of Smart Systems engagement in Automotive to other aspects of transportation, including Mass transit, Navigation and Infrastructure & Signalling.

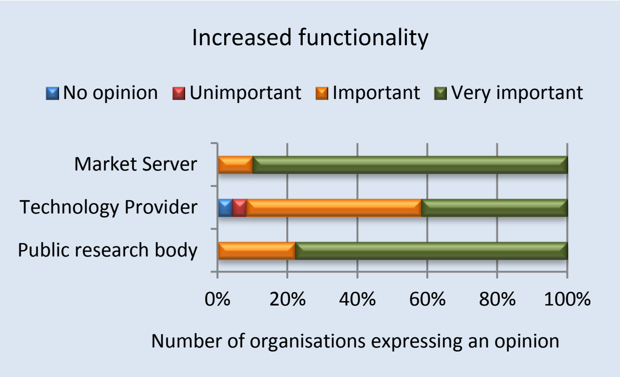
Drivers and barriers

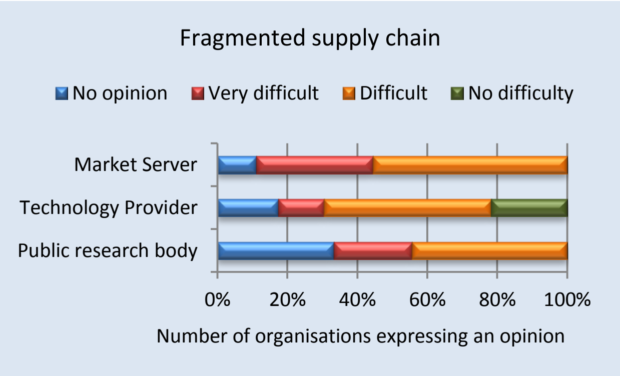
The survey of 63 Smart Systems providers to the Transport & Mobility sector rated "Increased Functionality" as the most important driver compared to, in descending order, Reduced Cost, Increased Reliability, New Markets, Global Competitiveness, Simplicity in Use, and legislative drives to compel the use of new devices or techniques.

The most obstructive difficulty reported was "Fragmented supply chain", responses indicating also that some 30% of public research bodies had no opinion about supply chain matters.

Accordingly, action should be considered to:

- Encourage researchers to gain better understanding of the Smart Systems supply chain to achieve a better match between research approaches and manufacturing capability.





The sector in more detail

Nowadays the car is still considered “the solution” to the demands for individual mobility, as it has evolved as the result of a process initiated one century ago and might now be expected to be a mature product.

Nevertheless, ever more demanding requirements in terms of sustainable, environmental mobility are forcing breakthrough solutions which will give rise to a significant discontinuity with respect to the past.

Due to different mobility needs there will be a further segmentation of the basic components: urban and extra-urban. As a consequence, the next challenge will be the identification of technical solutions able to cope both with the right to individual mobility and the requirements of urban and extra-urban regions.

As a result, and in more general terms, multi-modality, and novel concepts as e.g. the combined transport of passengers and goods will play a fundamental role in the sustainable mobility of the future.

In the past, the drives for technological innovation were mainly identified by cost reduction needs; but lately there has become a progressive shift towards:

- energy efficiency and fuel economy
- performances increase
- comfort and ergonomic improvement
- safety improvement
- emissions reduction

These items are still today top priorities, and will be the drivers for future technological evolutions in the perspective of sustainable individual mobility.

The sector and its subsectors

There is a sort of “red wire" which links Mobility and the other aspects of transportation, including Mass Transit, Navigation and Infrastructure & Signaling. In fact they share some global trends such as:

- Eco-sustainability and a progressive shift towards energy efficiency and alternative powertrains
- Improved connectivity and autonomy (for example through the Internet of Things)
- System availability and exceptional quality levels

Vehicles with alternative powertrains, and especially electric vehicles, may be the entry point for the massive introduction of e-actuators and x-by-wire technology on a very wide range of vehicles. In fact, in the coming years, several millions of vehicles, ranging from 2 wheelers up to busses, trucks and agricultural machines, will feature a wide range of components and systems which will be “smart” by nature. This in turn will call for novel platforms and novel E/E architectures.

Benefits of Smart Systems

Over the last 20 years we have witnessed an impressive evolution in automotive vehicles in terms of fuel efficiency, driving performance and active safety.

Automotive electronics has been the key enabling technology in those areas, fuelling and enabling innovation, and now representing more than 40 % of the entire vehicle's value (ICE technology). This percentage is much higher in the case of Hybrid Electric Vehicles and Fully Electric Vehicles, reaching up to 75% of the vehicle's value .

Currently we are facing a progressive "smartification" of automotive systems due to several reasons among which are:

- Centralized vs distributed architecture.
- Networking efficiency and communication payload.
- Packaging and interconnection.
- Plug and play
- A dramatic reduction of the whole product development time (including, for example, validation, qualification, calibration, ..)
- Massive utilisation across different vehicle segments and applications.

Hence, Smart Systems will play a relevant and rapidly increasing role for the sector and its subsectors, being fundamental and affordable building blocks in the development of the system, or product, as a whole.

The ability to design and develop better systems will also bring the ability to better address some societal challenges (for example energy efficient mobility, and hence less dependence on oil and lower carbon footprint, avoidance systems leading to less fatalities, introduction of automated driving, and many more possibilities).

Technical Challenges

The increased level of "smartness" to be provided by the next generation of Smart Systems, will require much improved real-time performance coupled with the capability to seamlessly integrate various components (for example passive and active sensors, actuators, ..) into a single unit.

Moreover the system "availability" level must be exceptionally high when it will be used in critical applications. In the case of safety relevant applications (for example ADAS, ABS/ESP, FADEC, etc) the hardware/software system architecture is going to be quite complex and must be compliant to emerging standards, such as ISO26262 and others.

To support the development of energy efficient vehicles and alternative powertrains advanced power electronics are needed that operate in demanding temperature regions. Active and passive cooling strategies have to be pursued. New generation of electric vehicles calls for innovative battery management enabled by smart systems. The future energy efficient vehicle requires highly integrated, high power density electric machines as well as optimized ICEs, increased integration of components and systems. All these are enabled by advanced ICT and electronic systems and components that are characterized itself by high integration and a high level of "smartness".

Another major challenge is the internal communication and the interfacing between the novel smart systems and components described above as well as the communication and the interfacing to the outside of the car.

Finally, standardization is a challenge in every respect for securing compatibility, safety and also for providing security regarding the market introduction of systems for the user but also the stakeholders in the automotive industry.

Introduction of Smart Systems

In the Automotive domain there are several applications where Smart Systems have been playing a very relevant role for many years. Through this experience it is easy to foresee further improvements, both in terms of performance and in terms of the "smartness" of the vehicle.

For instance, the electronic control of transmission (TCU) integrates the clutch/gearbox actuators, being either electro-hydraulic or electro-mechanical, and various sensors into a compact mechatronic system.

In most cases the TCU is incorporated into the whole transmission system and has to withstand severe mechanical and thermal conditions.

The first generation of TCUs provide simple and robust control of the actuators over the lifetime and according to different operation modes.

Then, the second generation of TCUs will cope with the actuators' parameter drift and aging; moreover it will perform sophisticated real-time diagnosis and analysis while also implementing several safety mechanisms.

Finally, the next generation of ADAS will be able to co-operate with other on-board system to build a consistent scenario. The system will be able to reconfigure itself in case of severe faults while providing the highest level of "availability".

European position

The automotive industry is a key contributor to the European economy and society. Europe is the world's largest vehicle producer with an output of over 17 million passenger cars, vans, trucks and buses per year, and represents about 6% of EU manufacturing.

This position has been achieved thanks to well established supply chains, and European vehicle manufacturers being global players, driving innovation towards cleaner, safer, and more sustainable transport.

The industry's product development activity is a strong asset, where technological and quality levels are extremely good. Nevertheless, as manufacture moves to low cost regions it is vital to maintain momentum in this field, with particular respect to high-tech and enabling technologies (for example energy storage systems).

There is a strong research base, demonstrated by a total of 8,568 patents being filed in the automotive sector at the European Patent Office in 2011.

Despite the remarkable achievements made so far, a political scale of long-term investment is needed to support the development of infrastructures for sustainable mobility and mass transport.

Moreover, special attention must be devoted to high level education, focusing on new disciplines and counteracting the declining numbers of engineering graduates.

The relentless race towards CO_2 reduction will drive the development of new powertrain technologies, where electrification will offer further opportunities for Smart systems. It also true that the continuous upgrade of regulations concerning emissions is causing an impressive effort, and huge hidden costs, for the homologation of new models.

In this context, ICT and smart systems and components because of their key enabling function will provide tremendous business opportunities, e.g. seamless multimodal travelling, for global market development.

Research overview

An integrated approach must be used to support sustainable mobility and multimodal transport with respect to:

- Highly integrated systems and components
- Energy management optimization
- Novel concepts for energy storage systems
- Power electronics for higher integration of motors and for demanding temperature regions
- EMC issues
- Optimization of energy need of auxiliaries and moving towards self-sufficient auxiliaries
- Revised ICT and E/E architecture
- Vehicle automation to support safe and energy efficient driving
- Standardisation of interfacing to the infrastructure
- The integration of existing base technologies and new ones for navigation.
- A unified semantic for sensors, especially with reference to the Internet of Things.
- Data security aspects related to the integration of nomadic devices.
- The integration or upgrading of older vehicle into the new infrastructures.

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Smart Systems for Transport & Mobility: EU Strengths & Research priorities

Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Sector as a whole	• EU global players have the necessary muscle to develop Smart Systems and to establish their acceptance and appeal	• Smart Systems value chain not clearly defined and recognised	• Smart Systems need a new class of "applications aware" multidisciplinary engineering teams	• Reliability issues not fully explored regarding autonomous Smart systems • "Cyber attack" of Smart vehicles and transportation systems
Automotive	• Innovative small companies and >6000 sensor producers • Well established supply chains	• Incremental development based upon improving previous models can hold back revolutionary Smart Systems	• Electrification brings new spaces for Smart Systems • CO_2 reduction is a further driver, with Smart Systems will bring higher efficiency and cleaner operation	
Mass Transit	• Huge installed infrastructure with "Smart" ticketing and some driverless systems already accepted by the travelling public	• The timescales of long-term infrastructure investment can fail to recognise and intercept with future technologies such as Smart Systems	• Resilient multimodal seamless Passenger -centric and goods-centric. travel. • Retro-fit new technology into existing infrastructures	
Navigation	• Good GSM and other infrastructure	• Basic display and Human Machine Interfaces are produced outside the EU	• Smart Systems to automatically gather and update geopositioning information	
Infrastructure & Signalling	• An already well regulated transport system to build upon	• Legacy systems need to interface with Smart Systems	• Use Smart Systems to optimise existing infrastructure at relatively low cost – more capacity on existing routes	• Regions of the world having a "clean sheet" for infrastructure could develop Smart Systems free from "legacy" constraints

Sub-sector	Priority actions	Mid-term actions	Longer term actions
Sector as a whole	• Unified semantics for sensor systems around the Transport & Mobility sector and the wider Internet of Things • Scale up Erasmus Mundus to create a new class of "applications aware" multidisciplinary engineering teams		• Reliability issues not fully explored regarding autonomous Smart systems • Cyber security • Introduce Systems Level Design as a curriculum subject
Automotive	• Innovative comprehensive battery management systems (BMS) and standardization of BMS components and interfaces • integrated electrified accessories in order to improve energy efficiency • advanced electrical/thermal monitoring systems • Develop Devices for Automated and Cooperative Driving • Generate new procedures to ensure that Smart Systems are "Automotive Grade"	• Integration of sensors, actuators and power electronics into components • Optimized integrated power electronics including advanced thermal management and cooling strategies • Standardisation for integrating the Smart vehicle into developing infrastructures	• Fundamentally revised E/E- and Software Architecture: Integration, Simplification, Flexibility
Mass Transit	• Identify the key points at which Smart Systems could provide significant benefits in existing and future Mass Transit systems, and quantify those benefits	• Provide Interfaces for Integration into Transport System Networks; Enable multi-modality	• Establish a mechanism for long-term infrastructure developments to intercept with rapidly developing Smart Systems technologies
Navigation	• Secure linking of personal nomadic systems to vehicle systems, mass transit systems	• Exploit ADAS for safety	• Enable fully automated driving for defined situations/applications
Infrastructure & Signalling	• Research the technical capacity in the existing infrastructure for the installation of smart upgrades, and determine new strategies accordingly	• Enable Car2X Infrastructure • Provide devices and communication protocols for bi-directional charging of EV	• The integration or upgrading of older vehicles that do not have Smart System capabilities, and formulating an upgrading process for Smart vehicles

Quick links:

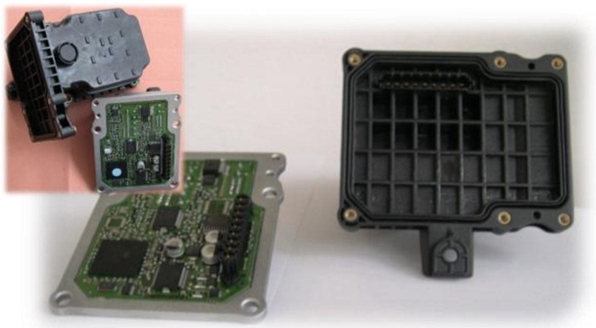
Sector overview | Automotive | Mass Transit | Navigation | Infrastructure & Signalling

Automotive

Overview

Smart systems affect every aspect of automotive. A great number of sensors, actuators and processors are already in place in today's cars, so the opportunity is to further install "smartness".

In the long term the societal challenges require significantly higher energy efficiency, lower CO2 and noxious emissions, a new vision of autonomous vehicles and novel concepts for individual mobility within the entire mobility system where the vehicle will be integrated and will interact into a much larger eco-system.



Selespeed Robotized gear-box Control Unit - *Magneti Marelli*

Opportunities for Smart Systems

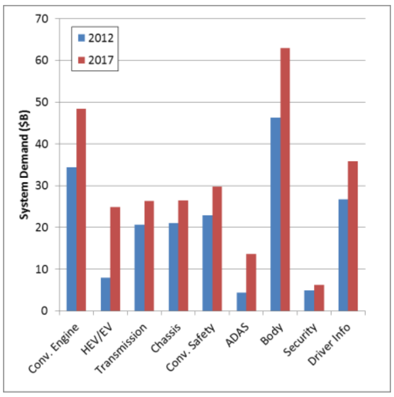
- Much intelligence integrated already, in all vehicles, and particularly at the heart of the EV
- Smart Systems enabling energy efficiency e.g. through integration and inducing synergies
- Optimise range, performance, comfort
- Smart e-actuators.
- Safety.
- Smart driver assistance.
- Optimise driver decision making and navigation.
- Health and Usage monitoring.
- Real-time sensor fusion and virtual sensor creation
- Smart "shell" design and implementation

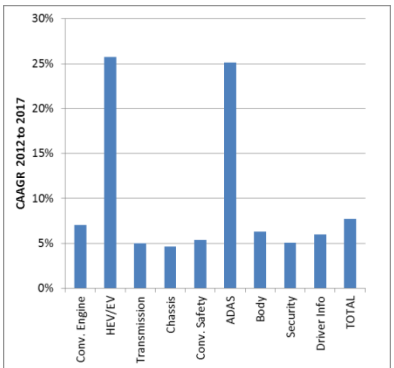
Hurdles to be overcome

- Re-inventing architectures – simplifying, localising, distributing. Trade-off from local to remote.
- New materials (SiC)
- Higher demands on thermal management
- Real time processing performance and multi-core platform.
- Affordable solutions for safety relevant applications.
- Consumer Electronic meets Automotive.

Applications

According to some in depth analysis ("Smart Connectivity: Connected Automotive Systems" B. Bihr, President Bosch Engineering GmbH, June 2012) there will be about 7bn connected people and about 1bn licensed connected vehicles worldwide by 2015. Moreover, due to the capability of HEV/EV to manage electrical energy on-board, it will become natural to consider the vehicle as a user/producer of electrical energy. As a result, the vehicle will interact in the Internet of Things (IoT) and Internet of Energy (IoE). Hence, there will be important opportunities for Smart Systems both in consolidated (powertrain, chassis, body,..) and new domains.





Source: Strategy Analytics Data Jan 2013

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Current wide application of algorithms in automotive emissions, fuel injection and combustion. Further applications are being developed continuously.

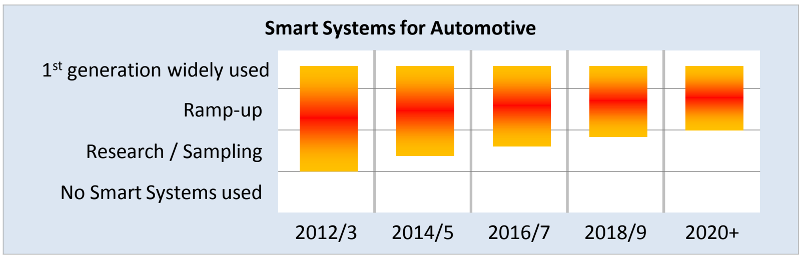
2nd generation Smart Systems are predictive and self-learning.

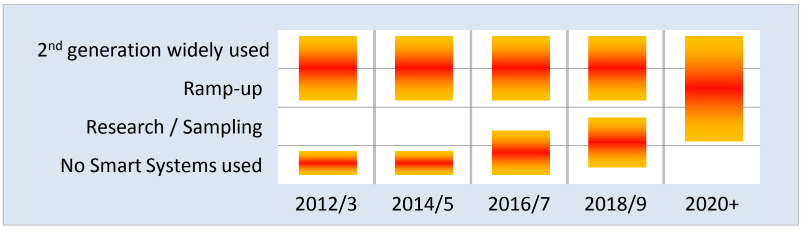
A major issue is to deal, over huge production volumes, with tolerances and aging of key components. Hence the systems must learn, react for the cleanest combustion process and store.

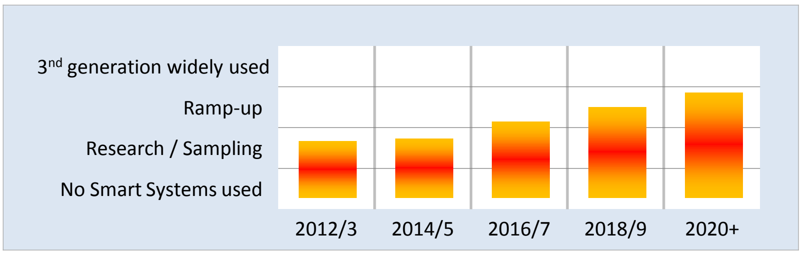
3rd generation Smart Systems simulate human perception/cognition.

Co-operative rather than self-organised systems are expected.

Evolutionary (self-reconfiguring and healing) hardware is under development



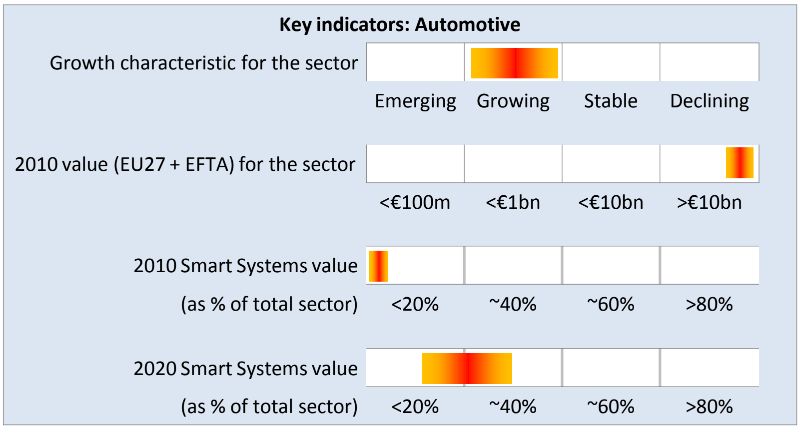




Sector forecast

Electronic systems are already 40% of the value of a car and will represent up to 75% in HEV/EV. In 2012, the global market for automotive electronics systems was worth $189bn, a rise of 11.2% over 2010, despite challenging economic conditions in many parts of the globe. The value of the world-wide market for automotive electronic controllers (ECUs) stood at $51.1bn in 2011.

The market is expected to continue to grow, due to the high-value of vehicles (inc. hybrids), with demand now expected to increase to $263bn by 2016. ADAS and HEV/EV are the major growth drivers, especially in established production areas. The total automotive sensor market in 2011 was $15.4bn, where Europe remains the largest automotive sensor market, with an expected value of $6.3bn in 2019.



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Quick links:

Sector overview | Automotive | Mass Transit | Navigation | Infrastructure & Signalling | EU Strengths & Research priorities

Mass Transit

Overview

The transport industry at large is responsible for generating 7% of European GDP and 5% of employment. The mobility of people and the flow of goods to, from and within Europe must be cost effective, safe and environmentally sustainable (currently the sector is responsible for the emission of 23.8% of green house gases and 27.9% of CO_2 and is 97% dependent on fossil fuels).

Today many bottlenecks in the road, rail, sea, and air transportation infrastructure prevent the creation of new links. A “green corridor” concept could be used for highly-populated multimodal corridors in Europe together with highly advanced co- and intra-modal hubs.

Opportunities for Smart Systems

- Infrastructure, rolling stock, control & command.
- Services to users (inc ticketing, journey planning).
- Freight, stock and infrastructure maintenance.
- Better capacity, lower cost, lower environmental footprint, reliability and availability.

Hurdles to be overcome

- Advanced positioning and communication systems
- Stronger safety and security of mainline and urban transit.
- Support to autonomous driving.
- Augmented vision using HMI (Human Machine Interface) and real-time sensor fusion techniques.

Applications

It is considered vital for the mass transport sector to develop new smart concepts such as modular load-carriers and innovative complete vehicle solutions (including the trailer) contributing to adaptable, tailored, efficient and seamless transport. Increasingly complex yet flexible logistics will also support dynamic changes in transport patterns. Finally, intelligent vehicles and transport services need to be supported by smartness in the road infrastructure. Future applications will deal with:

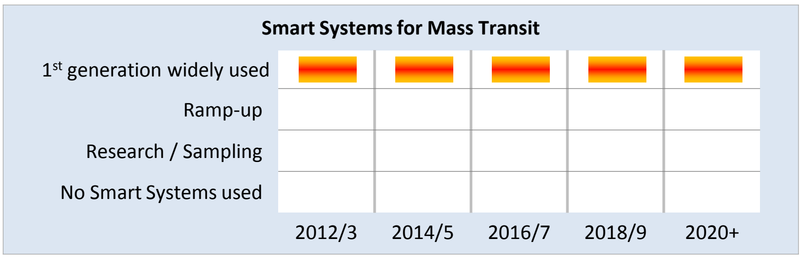
- Smart cluster for driver assistance.
- Multi-modal Shift-2-Rail, U-Bahn, Metro, Trams.
- Driver Coaching Systems (DCS) for eco-driving/fuel efficient driving.
- Advanced HMI supporting the driver and HMI-based information on cargo; smart driver cabin.
- Smart loading based on intelligent goods, and interfaces to the Internet of Things

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

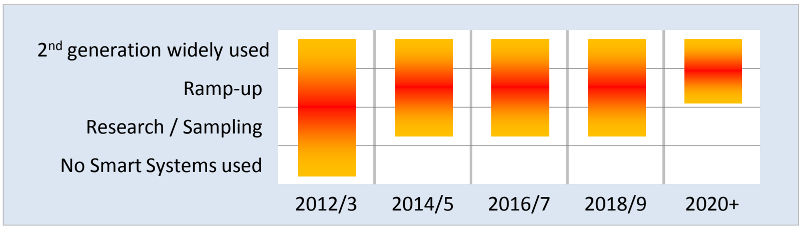
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

DCS gather vehicle's information and support the driver in eco-driving.



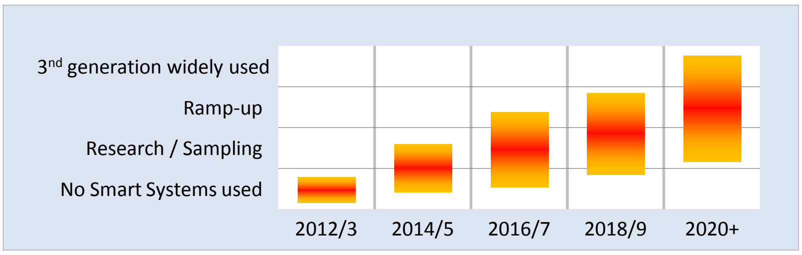
2nd generation Smart Systems are predictive and self-learning.

Smart systems for logistics: learn from the environment and interact with the other entities using, for example, swarm techniques.



3rd generation Smart Systems simulate human perception/cognition.

As driving becomes increasingly automated, future DCS will focus more on strategic aspects of driving performance rather than vehicle control.



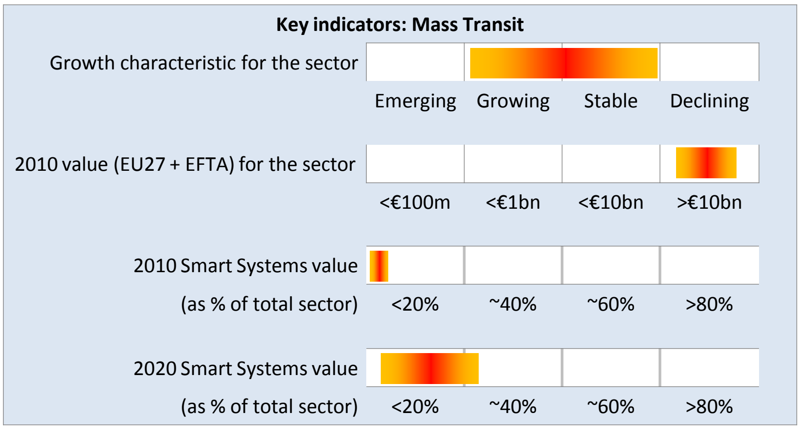
Sector forecast

Due to its direct link with economic growth, mass transit will grow much more strongly than personal transport. The challenge is to accommodate this growth on the available infrastructure maintaining adequate service levels.

Multi-mode travel will increase largely through the implementation of Smart Systems throughout the infrastructure and in customer service.

R&D is required to enable the implementation of highly-populated, multimodal freight corridors. In the long term interactive corridors will be based on V2V and V2I communication.

The target to be achieved by 2030 is to improve mass transport efficiency by 50%, based upon decarbonization, reliability and safety.



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Quick links:

Sector overview | Automotive | Mass Transit | Navigation | Infrastructure & Signalling | EU Strengths & Research priorities

Navigation

Overview

Tight interaction between Navigation systems and Advanced Driver Assistance Systems are on the route towards fully autonomous driving. The current challenge is to develop modular ADAS applicable to all vehicle classes and, even more complex, to bring ADAS into cities.

Huge potential is envisaged in Pedestrian Protection, Park Distance Control, Park Assist and Lane Assist by means of High Level Data Fusion thus being able to deal with general traffic scenarios.

Opportunities for Smart Systems

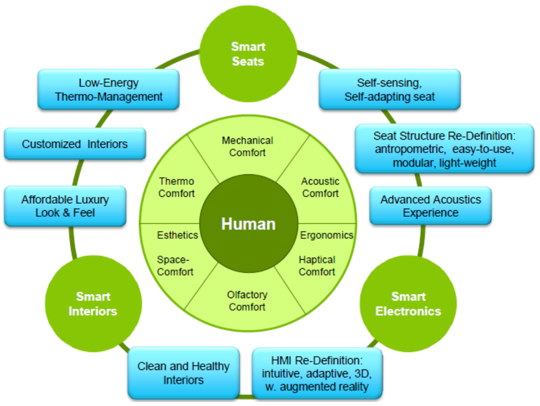
- Mode sensitive situationally aware vehicles.
- Pin-pointing emergencies – coordinating different forms of vehicle.
- Introduction of Car2Car / Car2X and Predictive Street Data in ADAS.
- HMI for augmented reality.
- Gesture recognition and drowsiness alarms.
- Flexible displays and smart upholstery.

Hurdles to be overcome

- Micro, meso, macro scale navigation.
- Complex environments on multiple continents and complex driver intentions.
- Radar sensor to avoid pedestrians.
- Detection of free spaces and parking.
- Maximum distance/speed resolution (using for instance 79 GHz and angular resolution via complex antennas)

Applications

- Satellites, interfaces to mapping
- In-building (e.g. inertial navigation)
- Navigation for things: Logistics:
- “Google drone” or monitoring on-line behaviour could reconfigure navigation and routes in real time
- Disruption prediction
- Evolution of ADAS: from Basic to Complex Scenarios and from Single to Networked Systems
- From Assisted Driving to (Highly) Automated Driving
- Support for autonomous ground vehicles



Introduction of three classes of Smart Systems

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1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

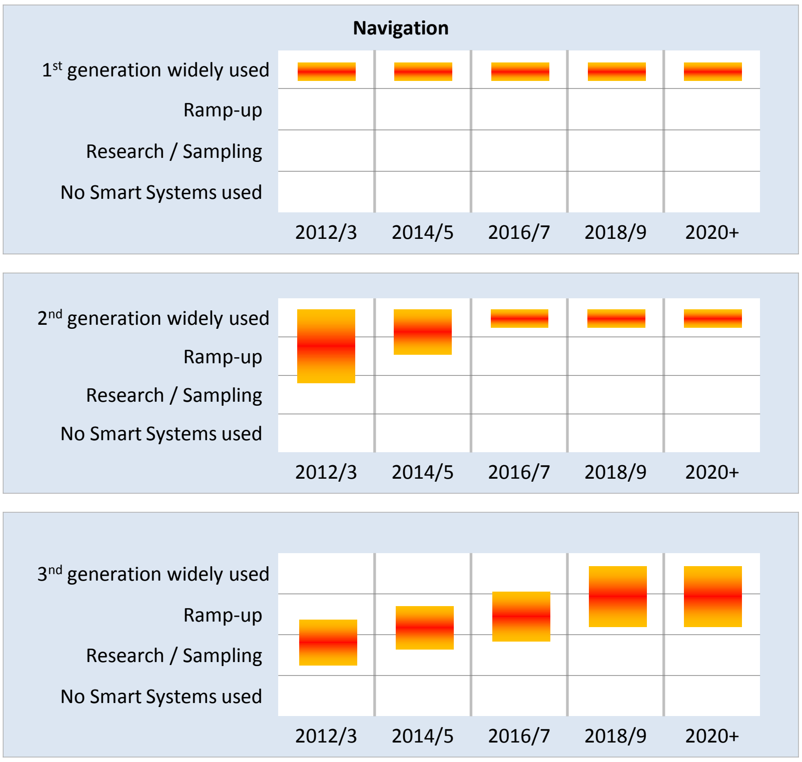
Current systems use a GPS navigation device to acquire position data to locate the user on a road in the unit's map database.

2nd generation Smart Systems are predictive and self-learning.

An electronic-horizon system will be provided in the next generation of PHEV/EV to support eco-driving and optimise routes according to the availability of charging points

3rd generation Smart Systems simulate human perception/cognition.

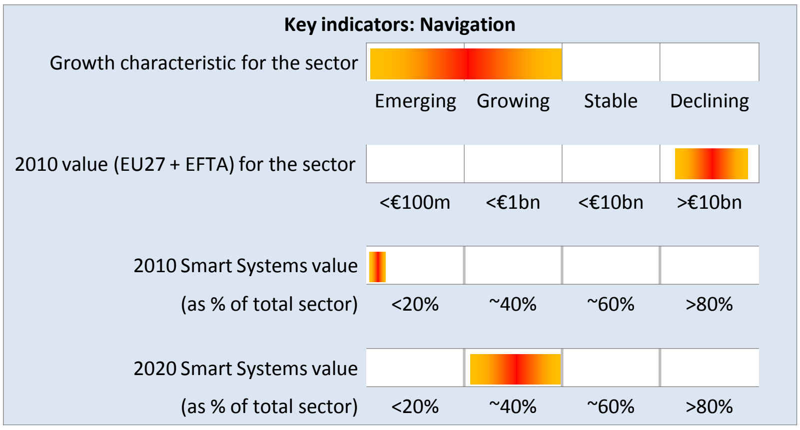
The vehicle will gradually take over more driving tasks. In the future. ACC will be enhanced with map data, such that it can automatically select set-speed and adjust speed in curves.



Sector forecast

By 2017 the market for automated driving support systems (collision warning, drowsiness monitors, night vision, e-call telematics) is expected to reach $7.6bn, representing a dollar CAAGR of 28.1 % over the period 2012 to 2017. With respect to the market for HMI and Navigation systems, sales are expected to reach $5.2bn, representing a dollar CAAGR of 9.8 % over the same period.

A very large growth opportunity is foreseen through the democratization of ADAS Systems into small vehicle classes through two mechanisms: reduced manufacturing price through increased volume, increased features to increase selling price.



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Quick links:

Sector overview | Automotive | Mass Transit | Navigation | Infrastructure & Signalling | EU Strengths & Research priorities

Infrastructure & Signalling

Overview

There will be a larger diversification in propulsion systems, energy-carrier, vehicle design and applications in the future. As a consequence the widest range of infrastructure must be envisaged to cover all form of transport and mobility, including goods road transport and person road traffic, individual and public concepts, 2- to 4-wheelers and new mobility solutions, delivery cars, trucks, buses, trams and trains, together with co-modality solutions. Smart signalling and the Internet of Things will provide the capability to monitor and report everything from in-vehicle to the proximity of other vehicles and entities.

Opportunities for Smart Systems

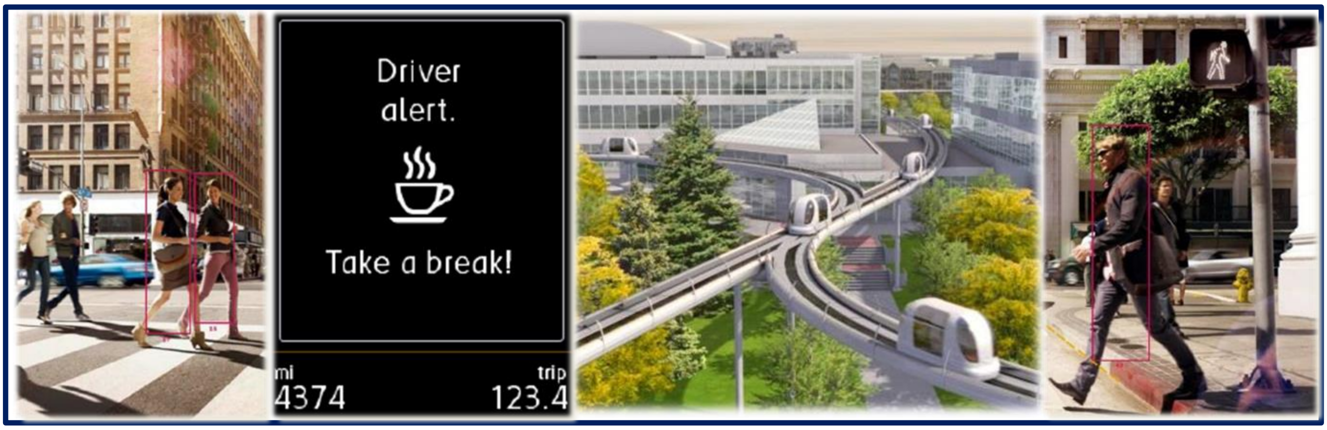
- Smart roads that indicate hazards.
- Co-operative systems of sufficient coverage and bandwidth.
- Predictive traffic planning, intelligent traffic management.
- Connection to energy supplies (including V2H, V2G) and charging/refuelling while parking/driving.

Hurdles to be overcome

- Management of high power in public spaces.
- Complex system integration and interaction.
- High investment for road infrastructure.
- Need for standardisation within Europe.
- Different cycle times of the different industries (for example: car – ICT – roads).
- Distribution of central control to a multiplicity of small self-organized units.

Applications

- Smart signalling that may reconfigure as users change behaviour, weekends, holidays, weather.
- Wireless and smart technology enabling real-time locating systems (RTLS) to support the process of testing and verifying vehicles coming off the assembly line while tracking them as they go through quality control, containment and shipping zones.
- Smart data collection from surrounding ‘things’, such as the vehicle parts themselves, the supporting transportation infrastructure (road/rail/etc), other vehicles in the vicinity, sensors in the loads being carried (people, goods, etc).
- Smart solutions for fare collection and toll systems, screening passengers and bags boarding commercial carriers as well as the goods moved by the international cargo system .
- Smart air freight containers (smartULD) with sensor monitoring, triggering alarms autonomously, Internet connected, ad-hoc networks of ULDs, energy harvesting, and integrated RFID-based identification of goods.

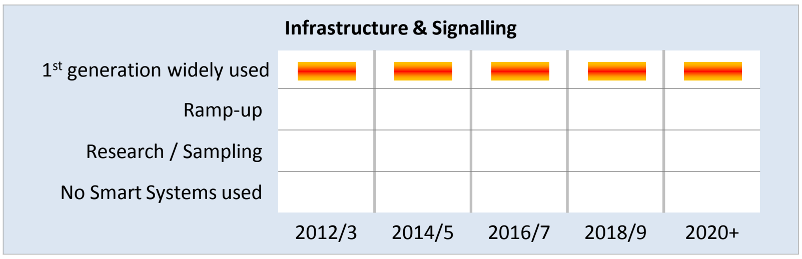


Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

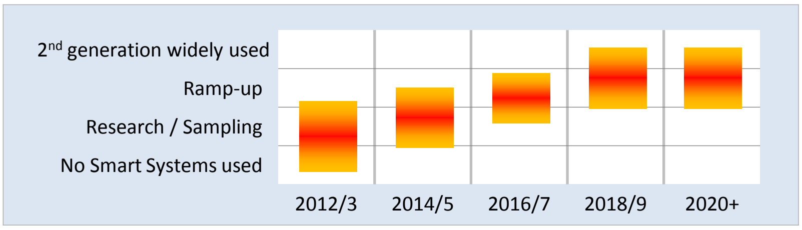
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Smart traffic lights already offer significant savings in waiting times and fuel consumption, gathering data from the infrastructure and control centres.



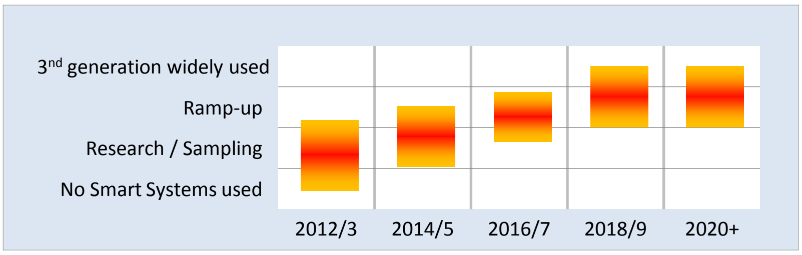
2nd generation Smart Systems are predictive and self-learning.

Active interaction through the traffic light whereby vehicles could send back information to optimize the traffic flow and to adapt the cycle time of the light.



3rd generation Smart Systems simulate human perception/cognition.

Cellular intralogistics and transport system: autonomous vehicles and modules (cells) cooperate like the cells of an organism.

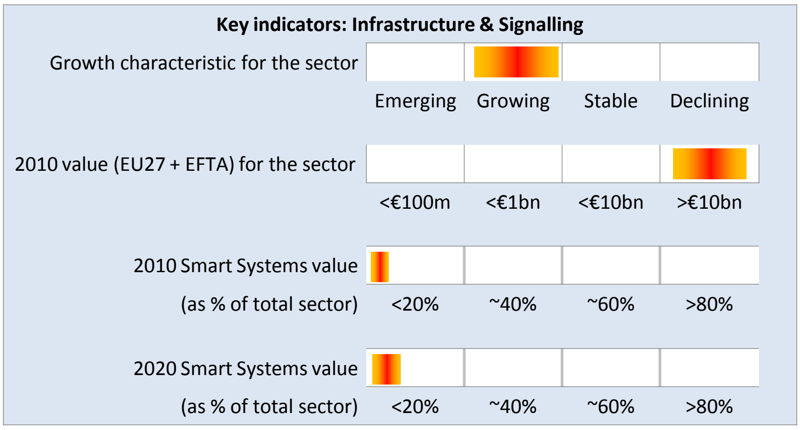


Sector forecast

There will be a tight link between the Internet of Things, signalling and logistics. The latter is Germany's third biggest industry, employing 2.8 million people (7% of total employment) with €220bn turnover in 2011.

In terms of education there are ~ 11,600 university graduates per year (BA and MA) with logistics references - mainly economists and engineers - 1.300 of these students major in logistics.

Hence Smart Systems will be a key technology supporting infrastructure such as smart roads, charge-while-driving and signalling. As with the electricity grid and the electricity supply changing step by step to a Smart Grid, any such infrastructure innovation cycle has to be recognised as protracted.



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Quick links:

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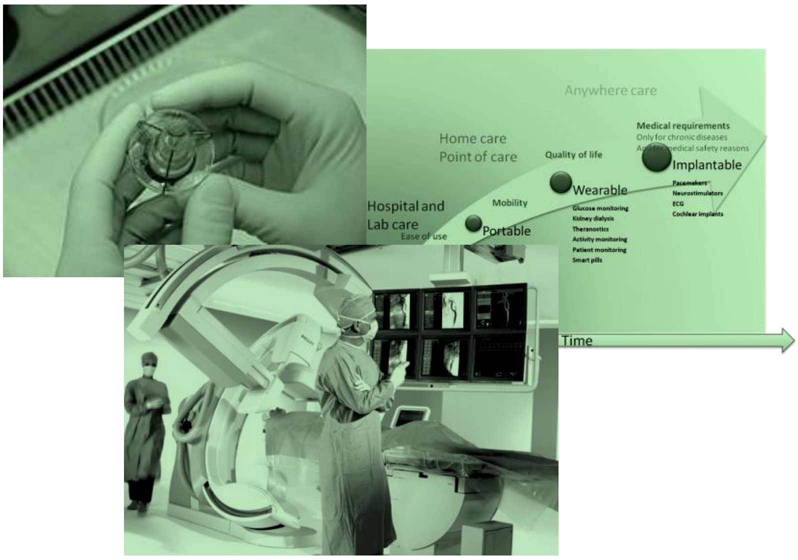
SMART SYSTEMS FOR HEALTH & BEYOND



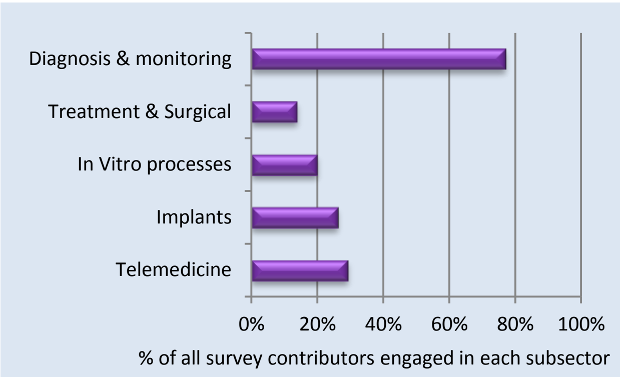
Smart Systems for Health & Beyond

Overview

Smart Systems, with their in-built adaptive capabilities and great potential for portability brought about by miniaturization, promise benefits across the whole spectrum of healthcare and wellbeing.

Applications include personal diagnosis, monitoring and fitness, treatment and implants, and ultimately to enhanced levels of telemedicine across the community.

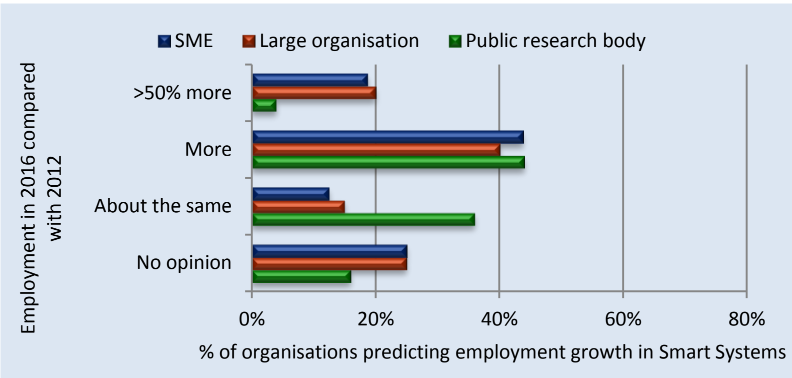
Ambulatory infusion system – *Smiths Medical*



Profile of subsectors

A survey of 58 Smart Systems providers, representing the supply chain from research through to market servers, revealed clear distinctions between subsectors (illustrated left).

Diagnosis & monitoring emerges as a current focus of interest in terms of the number of players, but the other fields, notably high value implants, would undoubtedly change the emphasis if the chart were to be presented in monetary terms.



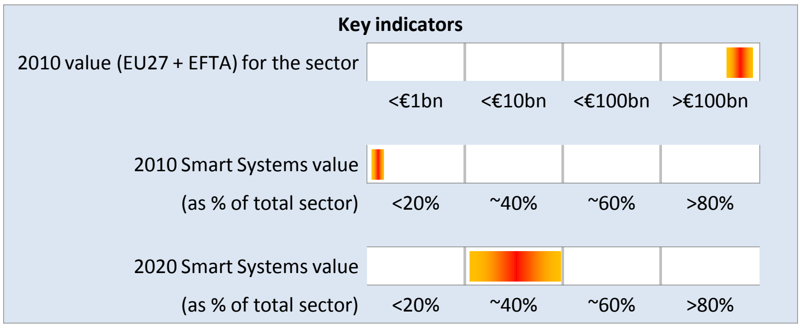
Growth prospects: Organisations

Of the Smart Systems providers surveyed, the great majority forecast employment growth, with a significant proportion of SMEs predicting headcount increasing by more than 50% by 2016 (illustrated left). There were no predictions of reductions in headcount

A similar picture emerged for growth in financial terms.

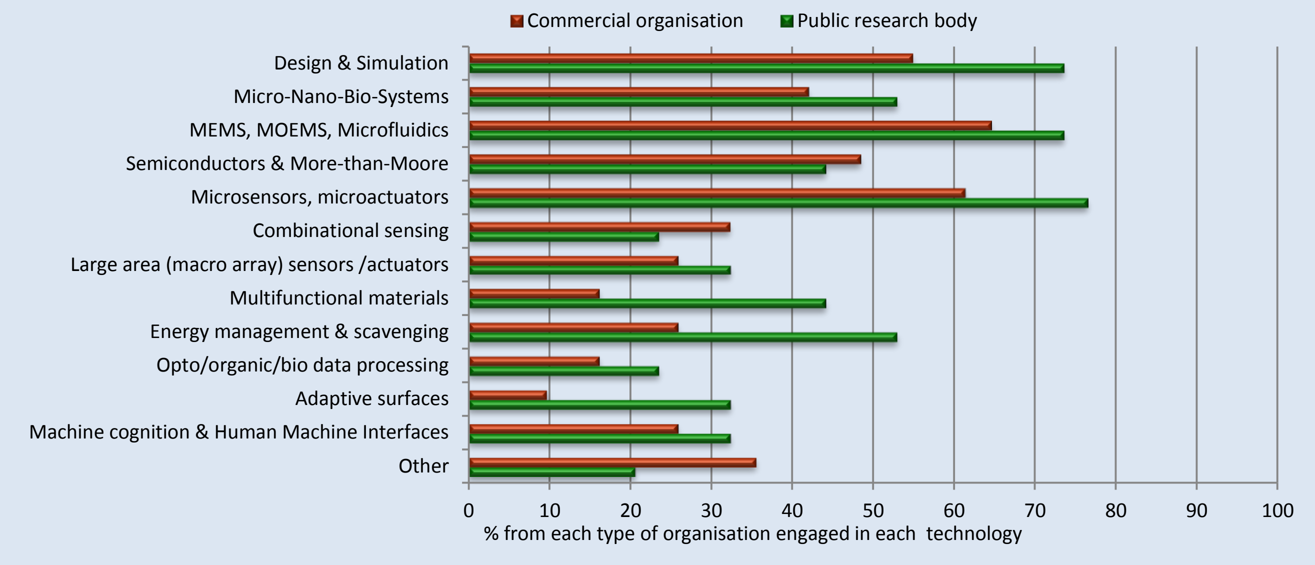
Growth prospects: Whole sector

The Health and personal wellbeing sector worldwide is immense in value: in 2011, $309bn (source: Vision Gain 2012) for the world wide medical device sector, including $90bn for medical electronics. Currently Smart Systems account for possibly ~10 to 12 % of this, but could rise to ~40% of the $130bn of medical electronics (> €50bn) by 2020 through wider adoption of Smart Technology in each of the subsectors examined.



The indicators above are shaded to reflect uncertainty

Underlying technologies



The five front-running technologies reported by healthcare companies were respectively: 1) MEMS, MOEMS & Microfluidics, 2) Microsensors & Microactuators, 3) Design & Simulation, 4) Semiconductor & More-than-Moore technologies, 5) Micro-Nano-Bio-Systems (MNBS).

Over 40% of companies engaged in healthcare reported use of MNBS technology, compared with some 30% of companies across the full breadth of Smart Systems applications.

A high proportion of Public research bodies report undertakings in Energy management & Scavenging, which seems to have penetrated rather less into commercial application than might be expected, considering the potential for the technology to power implants and body-worn devices.

Key issues for support should therefore include:

- Recognising and fostering the uptake of MNBS technology by the healthcare supply chain.
- Strengthening the exploitation of Energy Management & Scavenging technologies.

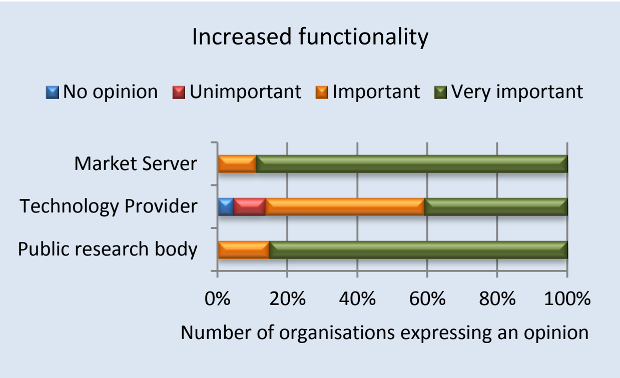
Drivers and barriers

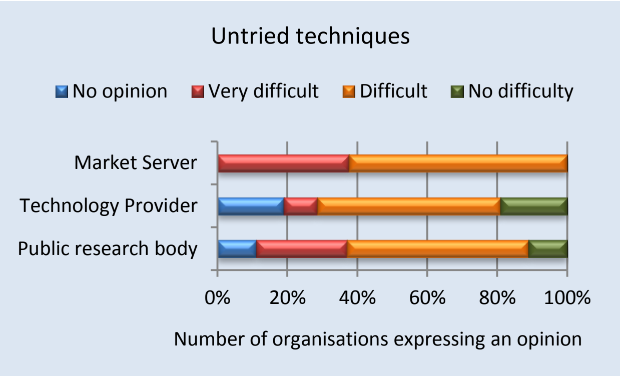
The survey of 58 Smart Systems providers to the Healthcare sector rated “Increased Functionality” as the most important driver compared to, in descending order, Reduced Cost, Increased Reliability, New Markets, Global Competitiveness, Simplicity in Use , and legislative drives to compel the use of new devices or techniques.

The most obstructive difficulty reported was “Untried Techniques”. This is instructive as the Increased Functionality Driver is most likely to be satisfied by Untried Techniques.

Accordingly, action should therefore be considered to mitigate the risks entailed in the uptake of Smart Systems for example by:

- Encouraging tighter inter-disciplinary R&D.
- Supporting the development of holistic simulation tools with coverage from concept, through manufacture to in-life service.





The sector in more detail

The UN predicts that by 2020 the EU27 population aged over 65 will exceed 100 million people with annual growth rate of 2% (an increase of 2 million people per year). This shows intensifying pressure on healthcare systems in EU27 and emphasizes the need for extremely efficient and cost effective medical devices for diagnostic and therapy delivery.

Health & Beyond not only presents opportunities for Smart Systems technologies, in fact progress may depend upon these technologies.

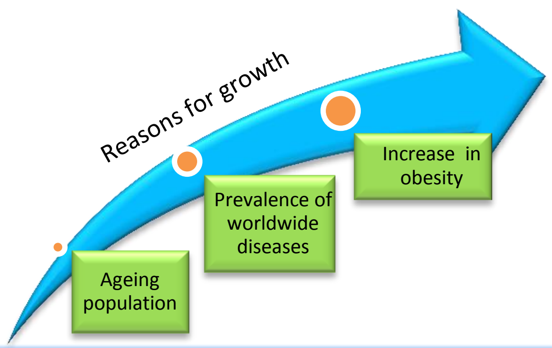
It is estimated that the annual medical devices spend in the EU was $74bn in 2011 in 2011 with a 4% annual growth factor (source: Vision Gain 2012), but the proportion relating to Smart Systems is difficult to evaluate precisely as this will vary from product to product.

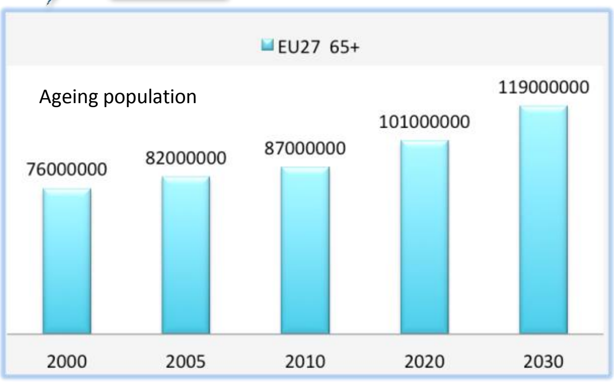
However, Smart Systems technology is, and increasingly will be, an inescapable enabling factor to address the growing needs of the Health & Beyond sector.

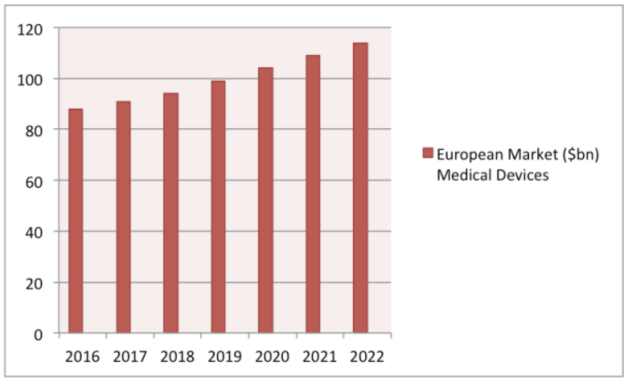
Breakthroughs and new generation services figure strongly in health sector innovations such as, for example, the substitution of drug treatment by smart active neurostimulator devices vs for heart failure, hypertension, depression, neurological diseases, and obesity.

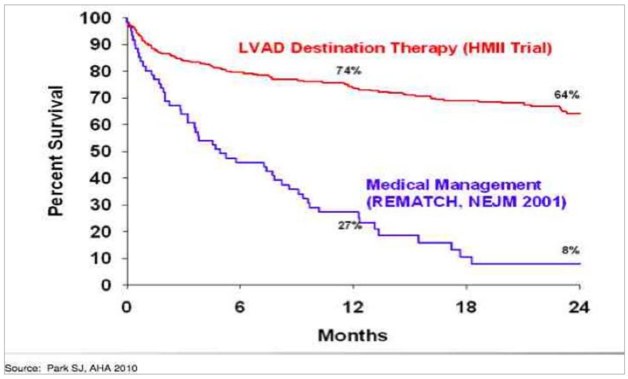
The emerging fields of neuro-interfaces and Brain Computer Systems depend not only upon the integration capabilities of advanced Smart Systems, but also upon in-depth and early communication between engineers, physicians and carers.

At the moment, the preservation of life, mobility and the senses is beyond price for a few happy pioneers, but cost effectiveness will be a necessity for wider deployment in the future.









The sector and its subsectors

Some individual subsectors are described later in this document, but it is instructive to consider a trend towards combination:

- Telemedicine might exploit biosensor data to update expert systems for diagnosis and in turn improve drug or minimally invasive therapy.
- In-Vitro Processes are expected to develop a new generation of micro implants
- Treatment & Surgical, implants and drug delivery may merge to become a single procedure.

"Electrification", it is very often thought of solely in terms of Electric Vehicles. This is wrong. Electrification will be pervasive through the massive introduction of e-actuators and x-by-wire technology on a very wide range of vehicles.

Despite these visions, it must be remembered that successful application will also rest with good business models, and an improved measures of added value and clinical outcomes versus cost.

Benefits of Smart Systems for Health & Beyond

Smart Systems have the capability to sense and extract physical and biological parameters which are recorded, analysed, transferred and acted upon. Accordingly:

- Smart Systems can provide a high level of sensitivity, specificity (molecular level) and reactivity, allowing appropriate actions to be triggered directly through micro- and nano-actuators.
- They can work in real time, and synchronized to internal or external events, or other systems, and linked together with other ICT devices and networks.
- A dramatic reduction of the whole product development time (including, for example, validation, qualification, calibration, ..).
- Massive utilisation across different vehicle segments and applications.

This will allow the detection of very specific patient information leading to a more appropriate therapy delivery, even remotely. And potentially Smart Systems will allow monitoring across large populations – improving the understanding of societal health and thereby further benefiting the individual.

The breadth of Smart Systems in Healthcare - *Sorin*

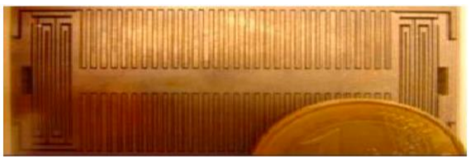
Technical Challenges

The survey of 58 Smart Systems providers showed that companies engaging with the Health & Beyond sector typically used multiple technologies in combination. This diversity precludes the formulation of a general view, save that the greatest difficulty reported was “Untried Techniques”.

Tighter inter-disciplinary R&D and the development of holistic simulation tools will assist in addressing these challenges.

Specific technological challenges were identified as:

- Energy harvesting to power Smart Systems from the surrounding environment.
- Micro/Nano technologies for biosensors.
- Scalable and secure low power communication with long range and networking layers.
- Packaging of Smart Systems in the lowest volume/size with appropriate costs.
- MRI-safe Smart Systems.
- Where required, long term stability and functionality in the hostile environments of body fluids and pharmaceuticals.



Energy harvester - *CEA*

Introduction of Smart Systems

Smart Systems have been used to a limited extent for many years in the Health sector, the first well known application being the implantable pacemaker from the late 1950s.

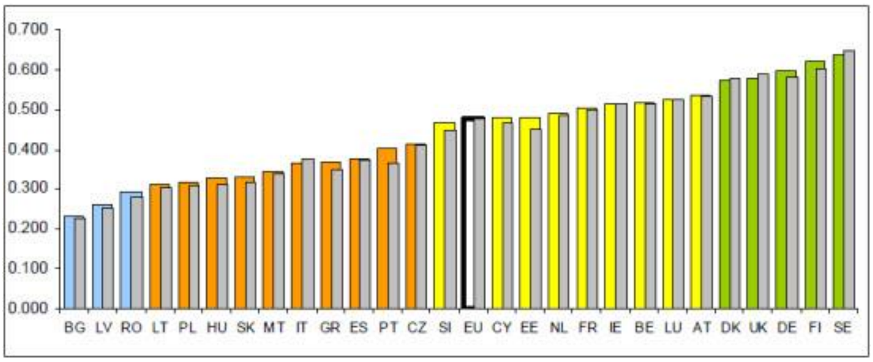
Today’s advances in Smart Systems derive from both incremental evolution as well as breakthroughs, and are leading to the integration of complex and sophisticated functions and capabilities, as illustrated by 2nd generation smart pacemakers incorporating several sensors and on time signal analyses allowing more discriminating, specific and reliable actuations with or without auto-adaptive functionalities.

A 3rd generation, in perhaps 10 years’ time, might allow the treatment of multiple physiological impairments in handicapped people, in organ failures or in neurologic disorders.

Pillcam - *Given imaging*

European position

Europe presents a strong research activity in the technology sector (vibrant sensor research, precision engineering, high quality level of engineers, robust supply chain with global leaders in semiconductors) and also in biology and medicine. A high level of education, world class knowledge, inventiveness and smart initiatives are well recognized and appreciated worldwide. These points constitute a strong position upon which Europe is expected to capitalize. The benefits promised by these strengths do however have to face and overcome European structural weakness due to market fragmentation, as compared with that of the United States which thereby also enjoys a dominant world position in the supply of medical devices.



2009 SII, summary of relative innovation performance of European countries

According to EUCOMED, the EU medical devices industry employs more than 575,000 people with 25,000 medical technology companies with almost 95% companies being SMEs, the majority of which are small and micro-sized companies. This has to be compared with a relatively consolidated 8,000 companies in US.

The EU medical supply chain needs to become more robust in order to compete with the larger US companies which acquire market intelligence in outside the US and invest massively in breakthrough enabling technologies in Health products/services, leveraged by powerful clusters.

Israel has for 20 years implemented a very dynamic environment to develop efficient and cost effective health products closely gathering financing, strong and pragmatic entrepreneurial will, high level skills and very dense well-connected swarms of start-up activities. This could prove to be an excellent model for Europe.

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Novel Harvester for cardiac Implants, Dal Molin et al. 2013

Smart Systems for Health & Beyond: EU Strengths & Research priorities

Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Sector as a whole	• EU has a developed health infrastructure and a conversant technology supply chain	• There are weak links between R&D, engineering and clinicians which hold back the introduction of "intelligent" Smart Systems	• Satisfy the need for pilot production players properly organised for the provision of small batches of specialised prototypes	• Slow regulation & administration processes may not cope with the knowledge/technology mix of Smart Systems
Diagnosis & Monitoring	• A system orientated approach, vibrant sensor research and skills in microbiotic approaches are ideal for Smart Systems development		• Smart Systems bring the techniques and skills of the laboratory direct to the Point of Care, and may for instance address "triage" with speed `and efficiency	
Treatment & Surgical	• European surgeons are leaders in various fields. Their needs and knowledge can be tapped.	• Surgical procedures not patentable in Europe	• The "functionalisation" of traditional instruments	
In Vitro Processes	• High level of cell biologist expertise to build upon	• Sensitive to ethical controversy	• Use Smart Systems to extend the use of multiplex biomarkers (today used in research and screening) into front-line diagnostics	
Implants	• Pacemaking. 40% from inside Europe, and leadership in cochlear implants: a strong "cluster for Smart systems"	• Merits of smartness have to be proved in EU for re-imbursement; easier and quicker in the US	• China and India are potential users, as Smart Systems can "broadcast" medical skill	• The barriers to entry and cost for Smart Systems providers, who may be newcomers to the sector, are very high
Telemedicine	• Good communications infrastructure, and a public conversant with social networking	• No clear reimbursement route, and medical organisations not appropriately prepared for a change in practices	• "Telemedicine in Europe" Initiative could augment the availability of medical expertise	• Timescales for organis-ational shifts can fail to recognise and intercept with future technologies such as Smart Systems

Sub-sector	Priority actions	Longer term actions
Sector as a whole	• Bridge gaps in the chain from research to exploiters, including better links between the medical/bio and engineering cultures through Smart Systems research industrialization and deployment schemes specifically for the Health sector • MRI-safe Smart Systems	• Tele-maintenance for autonomous instruments
Diagnosis & Monitoring	• A research spectrum spanning all the steps needed for Smart Systems to bring the techniques and skills of the laboratory direct to the Point of Care	
Treatment & Surgical	• Functionalisation of traditional instruments through Smart technologies • Secure minimally invasive treatment & surgery through Smart Systems integration • Develop Smart Systems to couple diagnostics with treatment • Autonomous wireless and self moving in body capsules for endoscopy and minimal invasive surgery	• Micro nano "clinical robotics"
In Vitro Processes	• De-skilling of procedures through Smart Systems to reduce operator dependence	
Implants	• Clinical studies for Smart Systems • Research to ensure full biocompatibility and stability, data and control security within the surrounding environment, and long term reliability for continuous chronic use in varied and challenging environments • Body energy scavenging for the power supply of artificial organs	• On-demand local manufacture of patient-customised "batch of one" devices
Telemedicine	• "Telemedicine in Europe" Initiative could augment the availability of medical expertise, sensitise and involve medical organisations, nurses, patients and relatives	• Tele-surgery

Quick links:

Sector overview | Diagnosis & Monitoring | Treatment & Surgical | In Vitro Processes | Implants | Telemedicine

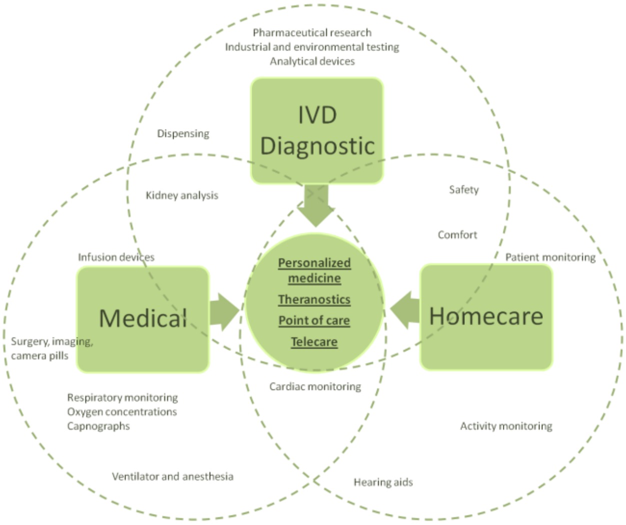
Diagnosis & Monitoring

Overview & Opportunities for Smart Systems

Diagnosis & Monitoring is multi-dimensional in the factors determining the use of Smart Systems:

- The nature of the parameters measured (physical, biological).
- The number of parameters (from 1~50).
- Patient access (biological sampling, endocavitary, surgery, endoscopy, wearable, implantable).
- The frequency of measurement.
- Location and environment (critical care, hospital, laboratory, doctor's clinic, at home/rest home).
- Differing evaluation of results (normal values, scoring, alerts), and the uses of results (patient triage, personalized care, disease/treatment monitoring, forensic).
- The potential combining with other functionalities (treatment, drug delivery).

Smart Systems, by combining observations and accurately inferring results, promise to reduce the number of individual biological investigations.



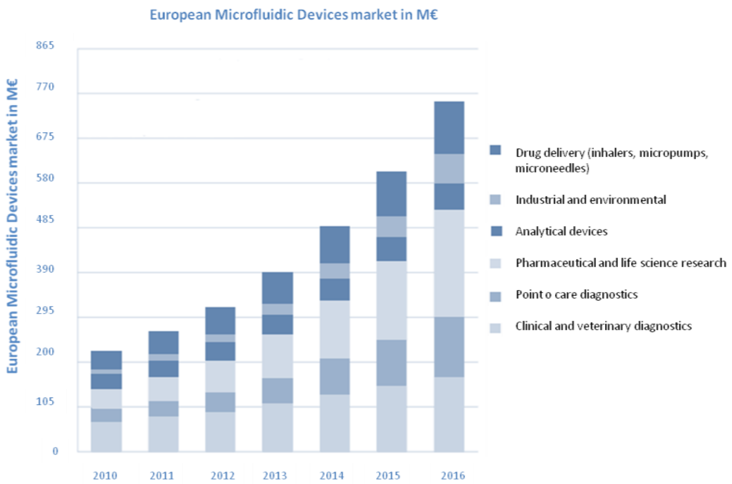
Intersecting fields of activity for medical devices - *Sorin*

Hurdles to be overcome

- A breadth of research is needed, spanning all the steps needed for Smart Systems to bring the techniques and skills of the laboratory direct to the Point of Care
- The EU's vibrant sensor research and skills in microbiotic approaches need to be combined for effective Smart Systems development

Applications

- European & FDA regulations concerning diagnosis and monitoring requires manufacturers to obtain a CE mark or FDA market clearance.
- The validation of claimed functionalities as well as their clinical relevance in daily practice involves the manufacturers, who must plan and pay for the validation.
- The in-built "knowledge base" of Smart Systems, and the veracity and safety of any autonomous action will require careful, and possibly lengthy, approaches.



European microfluidic devices market €m - *Sorin*

- Market access for Smart Systems in Diagnosis & Monitoring will depend not only upon the precise application, but also upon the specific geographic region. For instance, it could be faster and easier to reach the US market first (Central Laboratories, existing precedence), but no general rule exists. Even in the US, cost effectiveness of a new diagnosis must be documented in depth, but US players do appear to be quicker to adopt new practices, due to innate competitiveness.
- The purpose of diagnosis is to direct patient management. Smart Systems, with their combined sensing and actuation, are likely to generate new applications in diagnosis & treatment, diagnosis & surgical, and diagnosis & implants.

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

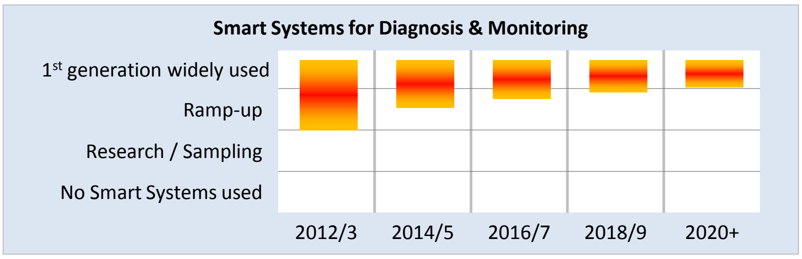
Exemplified by the implantable cardiac defibrillator: a sensor detects the lack of electrical signals and triggers electrical pulses to reactivate myocardium beats.

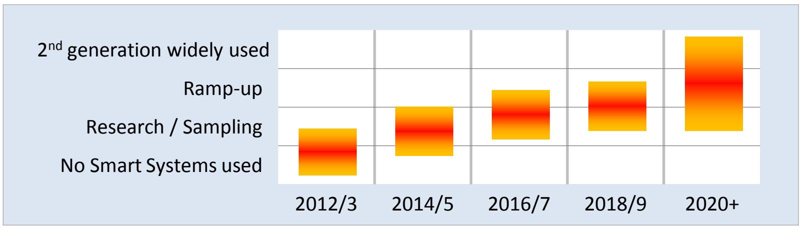
2nd generation Smart Systems are predictive and self-learning.

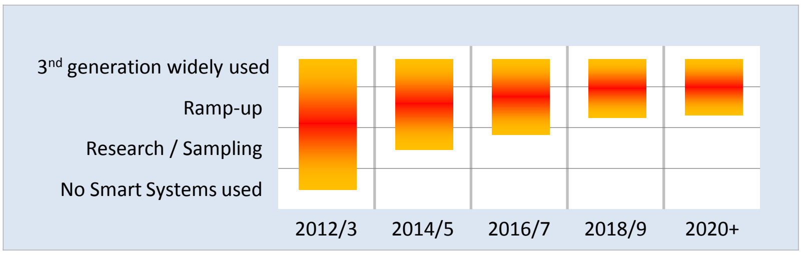
Cardiac Resynchronization includes an additional sensor to detect real-time patient condition for the optimisation of treatment and diagnosis of early signs of pulmonary oedema.

3rd generation Smart Systems simulate human perception/cognition.

BCI "Brain Computer interfaces" will open the door to continuous sensing and real-time smart signal processing allowing wireless activities for tetraplegic patients



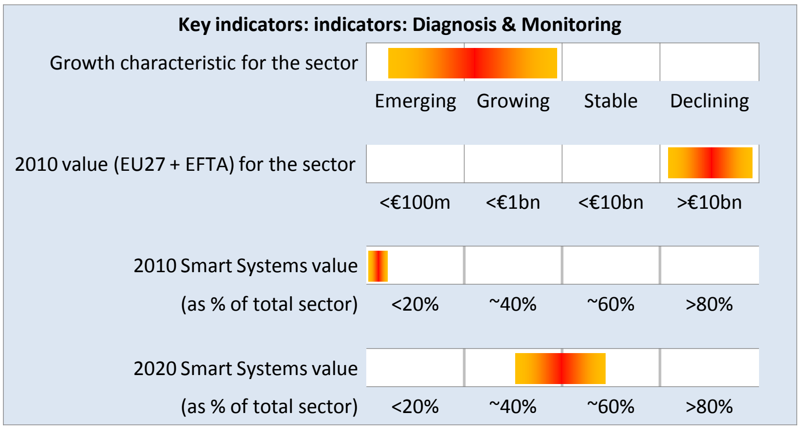




Sector forecast

The world-wide diagnosis market was estimated at $57bn in 2012, with an 8% annual growth rate. Part of this market might migrate to Smart Systems following:

- Better understanding of biomolecular physio-pathology that will allow multifactor approaches.
- The emergence of new clinical concepts, such as the relationship between the microbiote and diseases.
- The demand for multiplex diagnosis at the doctor's clinic.
- Smart developments in patient triage.
- New generations of combined medical products.
- The creation of Smart Systems to enhance clinical research.



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Quick links:

Sector overview | Diagnosis & Monitoring | Treatment & Surgical | In Vitro Processes | Implants | Telemedicine | EU Strengths & Research priorities

Treatment & Surgical

Overview & Opportunities for Smart Systems

Treatment, such as radiotherapy, High Intensity Focused Ultrasound (HIFU), laser and photon-therapy, often goes hand-in-hand with classical surgical procedures.

Together, the Treatment & Surgical domains share common issues of accurate targeting / positioning and minimising invasiveness.

Additionally, treatment requires the delivery of precise doses tailored to the needs of individual patients, while surgery has evolved towards precision endoscopy, keyhole and percutaneous (needle puncture) procedures.

Smart Systems, with their ability to combine multiple sensors and actuators, could extend the eyes, ears and touch of surgeons and treatment operators, guiding positioning and monitoring / analysing tissue status and the reaction of the patient.

Ultimately, robotics enabled by Smart Systems will come to the fore; however every smart tool must be designed to be used safely without recourse to lengthy training.

Applications

Beyond the new generation of Smart Systems and robotics in treatment and surgery, the sensing of brain or eye motion signals will lead to new medical approaches concerning neurological diseases/ handicap. This issue has already been highlighted in "Diagnosis & Monitoring" as sensing is the unavoidable step in the evolution of specific treatments.

BCI (Brain Computer Interface) technology promises a breakthrough in the understanding of human perception/cognition and conscious/unconscious motion or actions.

Currently, BCI needs significant computer power, electro-physiologists and highly skilled physicians interacting closely with signal analysis and data mining engineers.

This is an ideal scenario to distil into Smart System approaches, perhaps building upon technology from the computer gaming industry – and benefitting from a wide pool of user experience in that domain.

Beyond technology per se, for a product roadmap a balance needs to be struck between the main clinical benefits expected by disabled people and the technical complexity that can be applied in practice.

Cardiac example of links between treatment an surgery - *Sorin*

Hurdles to be overcome

- Balance the development of Smart Systems for very specific applications, whilst making the most of their ability for customisation.
- Tap the needs and knowledge of European surgeons, who are global leaders in many fields.
- Use Smart technologies to "functionalise" traditional instruments
- Through Smart Systems, open the potential for treatment and surgery for untrained end users at remote locations, incidents and disasters.
- Develop Smart Systems that are either sterilisable, or low enough in cost for single-use

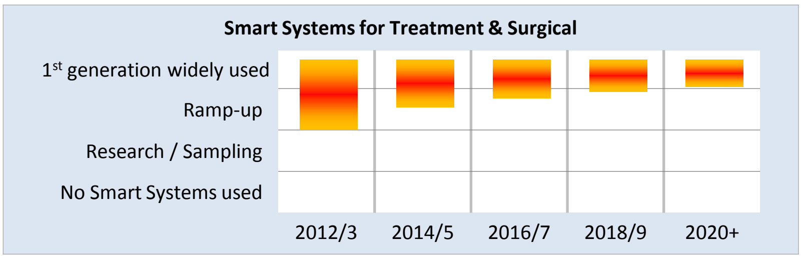
Wireless Electro Encephalography - *Starlab*

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

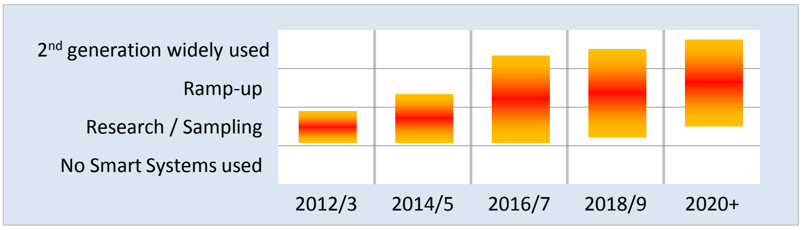
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

DCS gather vehicle's information and support the driver in eco-driving.



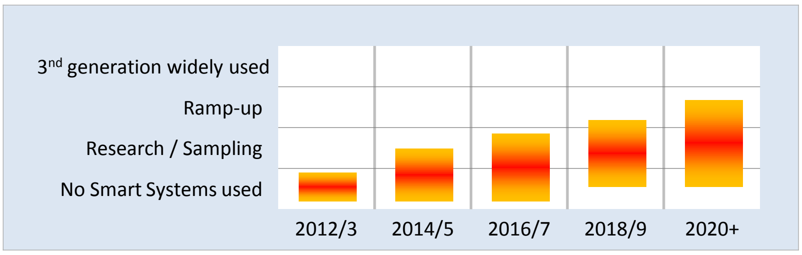
2nd generation Smart Systems are predictive and self-learning.

Smart Systems to direct and control High Intensity Focused Ultrasound (HIFU) treatment.



3rd generation Smart Systems simulate human perception/cognition.

Devices allowing communication thanks to BCI for tetraplegic patients or those suffering from Locked-in-syndrome.



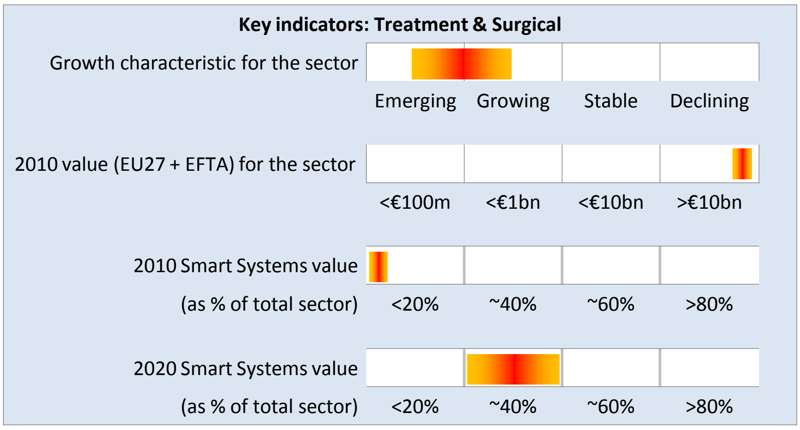
Sector forecast

Reduced invasiveness in surgery will bring significant cost savings in theatre-time and recovery time.

In the treatment domain, active devices need to be safer for the benefit of patients, for healthcare staff and for the environment.

Trends for minimally or percutaneous surgery are strong and continuing. Smart ancillaries, with the potential to reduce the time of invasive procedures and also to can be expected to provide strong incentives for the adoption of Smart Systems, whilst the targeted treatment of tissue will also constitute a strong driver.

Low prices for single use Smart Systems will contribute further to an increased proportion of Smart Systems across the Treatment & Surgical spectrum.



The indicators above are shaded to reflect uncertainty

Quick links:

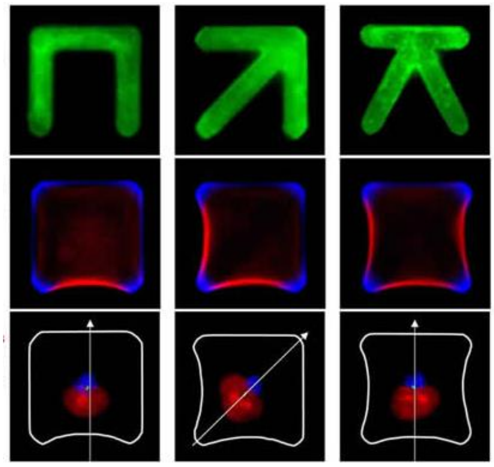
Sector overview | Diagnosis & Monitoring | Treatment & Surgical | In Vitro Processes | Implants | Telemedicine | EU Strengths & Research priorities

In Vitro Processes

Overview & Opportunities for Smart Systems

In Vitro Processes are an emergent activity. They promise to support new diagnostics and treatments through:

- Cell-driven "factories", for example magnet-producing bacteria, and bio-reactors for the production of proteins or customised reagents. Smart Systems, with their ability to track and optimise multiple parameters will find use in monitoring the bio-reactor environment - pH, pressure, liquid viscosity, O2, CO2 and other gases and nutrients – and then controlling the regime and duration of the process.
- Micromanipulation and triage at the cell level.
- Tissue generation processes, which are at the earliest stage of research. These might draw benefit from electrical or other stimulation, depending on sensed physical or biological parameters enabled by Smart Systems.
- The use of artificial tissues or organs which, although now only in early research, might see a true symbiosis between biology and engineering.



Micro-patterns for cell culture- *CYTOO Cell Architects*

Hurdles to be overcome

- In-vitro process control comprises closed-loop real-time requirements. What can be learned from other, non-health, domains? What will be the differences?
- Need close collaboration between physiologists, anatomo-pathologists and engineers. A forum is needed for this.

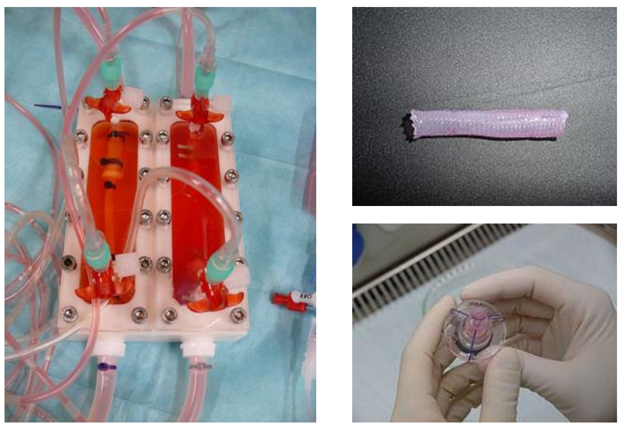
Applications

The path to application depends upon the intended use. Time to market and certification will be highly different between, for example, R&D, biological production or clinical practice.

For example, tissue engineering (intended for human use) must follow first the European procedure (Committee for Advanced Therapy, EMA), which is a long process. Furthermore, although tissue processing with Smart Systems could be seen as a breakthrough technology without significant regulatory references, such tissue engineering would involve, in addition to EMA, medical device regulatory bodies concerned with technological and medical device issues.

However, regulatory aspects of the ex vivo selection of abnormal cells or ex vivo stimulation of some white cells before re-injecting into the blood stream might be easier to overcome than the ones for complex tissues that involve more than one kind of cell.

The use of Smart Systems for the controlling and optimising of bio-reactor processing will not require the involvement of EMA or Notified Bodies when the end use is the production of molecules (proteins, antibodies, glycans, etc) or food. The time to market for such use will be easier to predict and control, and yield experience and familiarity that will assist the adoption of Smart Systems in the other aspects of the In-Vitro Processes domain.



Bioreactor for cultivation of vascular grafts,
Tissue engineered vascular graft and heart valve - *Wikipedia*

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

In vitro cell sorting to look for abnormalities for R&D purposes.

The control of cell chambers.

2nd generation Smart Systems are predictive and self-learning.

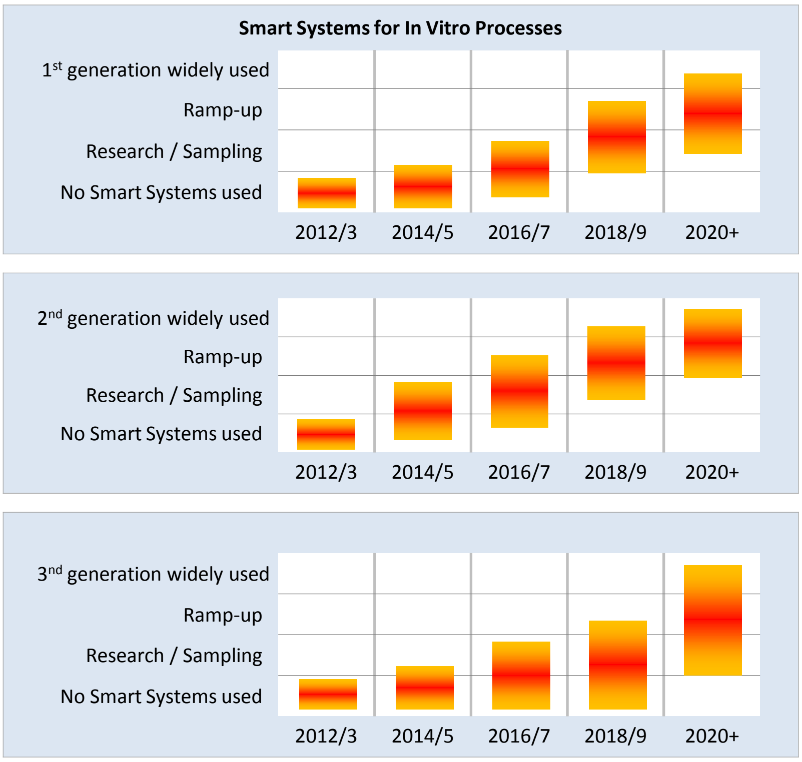
Ex-vivo identification of circulating tumor cells in blood for their removal.

Functional diagnosis combined with bimolecular mapping.

3rd generation Smart Systems simulate human perception/cognition.

Ex-vivo identification of circulating tumor cells for removal, and the stimulation of specific white cells (e.g. Killer cells).

Automated tissue matching and production.

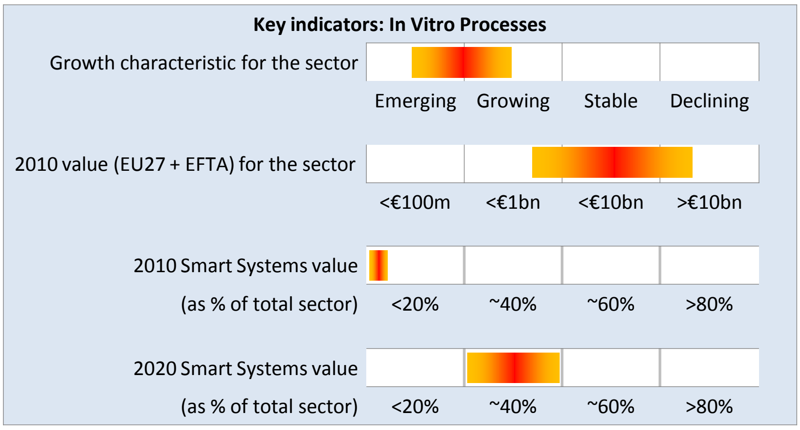


Sector forecast

As mentioned previously, time to market and therefore the growth characteristics for In-Vitro Processes depend very much on precise applications. Furthermore, these segments are not well established, so only coarse estimates can be made.

One can assume that the market related to Smart Systems used for controlling the physical and biological environment of bio-reactors will grow significantly by 2020 due to expected increases in the production of biological molecules.

For the Health sector as a whole, market growth might not be linear. An expected latency period will allow structuring the market, following which an inflexion in growth may occur, with Smart Systems piloting a few reliable and highly effective products to open the market.



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Quick links:

Sector overview | Diagnosis & Monitoring | Treatment & Surgical | In Vitro Processes | Implants | Telemedicine | EU Strengths & Research priorities

Implants

Overview & Opportunities for Smart Systems

Implantable devices constitute a growing market, driven by the potential to find solutions for organs, tissues or physiological function failures. Fundamental, pre-clinical and clinical research efforts are both huge and fruitful, and are leading to a wave of opportunities for Smart Systems:

- Active cardiac implants (with the addition of new functionalities,)
- Neurostimulation: new generations of existing implants; and new applications, in, for example, hypertension and neurological disorders
- Cochlear implants. Retinal implants
- The opportunity also includes smart products for organ replacement during surgery, short to long term convalescence, and recovery products.

There are many common factors driving the above opportunities: wireless, miniaturisation, adaptability to the patient status with time, skill-free autonomy, MRI compatibility, longer chronic use, less invasive, remote control and maintenance, and remote parameterization.

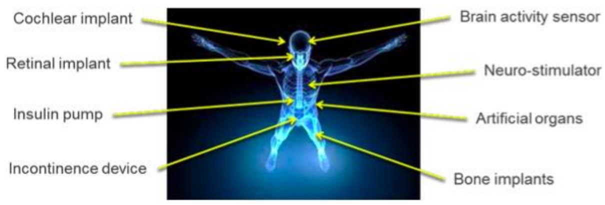
Applications

Aside from cardio and neurostimulation, which constitute well defined sub markets, other implants using Smart Systems technology are emerging.

- Percutaneous then implantable drug delivery systems are expected to be developed by 2020. This could be through incremental migration from existing wearable technology, for example insulin pumps, or by technology breakthroughs such as active micro 3D lab-on-chip.

  Drivers for such new products will be the enabling features of Smart Systems combined with a recognition of clinical and societal cost effectiveness and efficiency, and a broadening of application to include, for example, schizophrenia and the chronic local treatment of endometriosis and tumours.

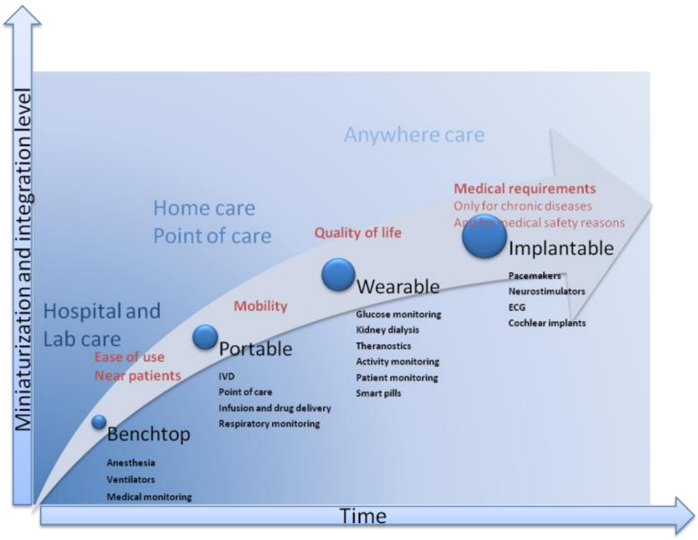
- Smart versions of previously wholly “structural” implants (for example hips) might record usage, loading, wear and predict useful life.
- All the implantable devices with Smart Systems will belong to the EU Class 3 classification.



Opportunities for implants - *Sorin*

Hurdles to be overcome

- Full biocompatibility and stability.
- Data and control security within the surrounding environment.
- Longer chronic use, requiring long term reliability in varied and challenging environments, including exposure to EMI and MRI.
- Remote control and maintenance.
- The barriers to entry and cost for Smart Systems providers, who may be newcomers to the sector, are very high.



Evolution of medical devices towards implantation - *Sorin*

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Implanted veterinary identity chips are simple, cheap and made in volume.

Simple, safe, pacemakers in wide use

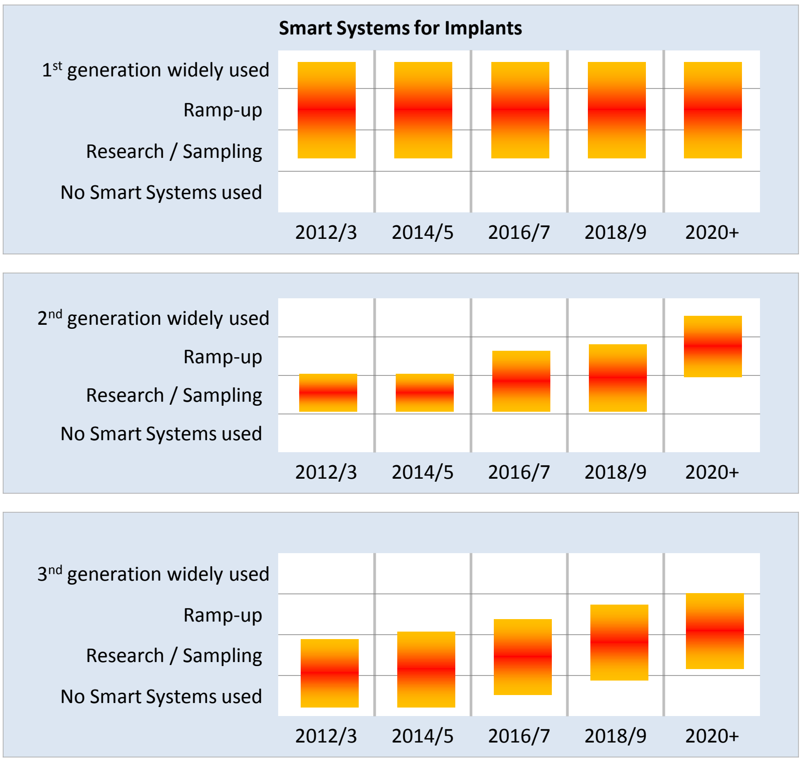
2nd generation Smart Systems are predictive and self-learning.

Innovations in intracardiac sensors and new generations of defibrillator will rely on Smart Systems technology for highly adaptive functions.

3rd generation Smart Systems simulate human perception/cognition.

Adjustable deep brain stimulation.

Adaptive and reversible neuro-stimulation for obesity, hypertension, improved cardiac contractility and reduction of arrhythmia.



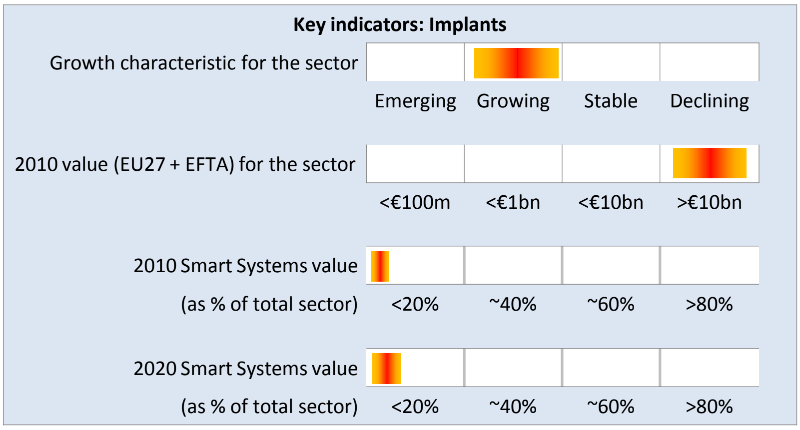
Sector forecast

The world market for neurostimulation is forecast to be $6.9bn to $7.3bn in 2018 compared with about $4.2bn in 2012, driven by the expanding number of diseases treatable by this technique.

The cardiac market is forecast to be $5.1bn in 2018.

Forecasts for other active implant product sectors is not so easy. As an example, the wearable/percutaneous insulin pump market is forecast to be $1.2bn by 2017, compared to the total insulin delivery device market estimated at $11bn. This increasing market penetration will lead to valuable opportunities for Smart Systems.

[References: Global Industry Analysts, 2012; MarketandMarket, 2012; Laurier Global Citizenship Conference, 2012; Global Data 2011/2012]



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Quick links:

Sector overview | Diagnosis & Monitoring | Treatment & Surgical | In Vitro Processes | Implants | Telemedicine | EU Strengths & Research priorities

Telemedicine

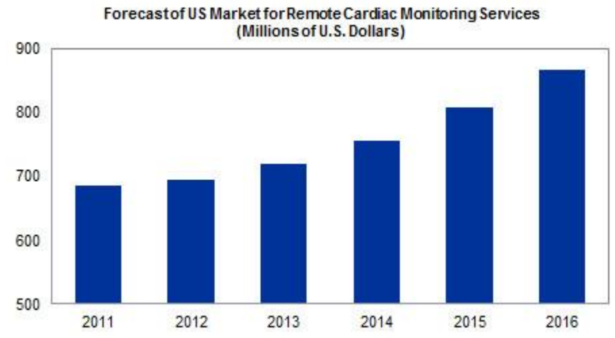
Overview & Opportunities for Smart Systems

This sector involves many players: patients, relatives, carers, nurses, doctors and physicians - at home and care homes, in clinics, hospital wards and operating theatres, first responders, and the health organizations, insurance companies and service providers who finance healthcare.

The clinical and societal applications of telemedicine are likewise diverse: the remote monitoring of chronic disease, disabled people, child pathologies and ageing people, remote risk or behaviour assessment, and the tele-observation of wearable medical devices and the treatment that they provide.

Moreover, telemedicine spans from basic remote tracking to 'face-to face" interaction between clinicians, the transfer/processing of images, and the conveying of critical clinical alerts.

The devices involved - wearable, implantable, portable and on-line including smart phones and tablets – present major opportunities for the application of Smart Systems.



Source: IHS InMedica Research February 2012

Hurdles to be overcome

- Finding the right pilot applications in terms of individual patient interests, cost/benefit effective-ness and improved resource use in care units.
- The provision of privacy, interoperability, data security, EMC immunity and fail-safe reliability, all to life-critical standards at low cost
- The development of approaches to data mining and a hierarchy of actions upon the data analysed, from individuals and from the population at large..

Applications

The telemedicine market, being new, has yet to reveal a definitive structure. Each day, new applications are proposed, with efficiency and value yet to be proven.

- Patient monitoring devices are already numerous, such as for blood pressure, oxymetry, glucose, prothrombin time, EEG/EKG, fetal heart monitors, TENS (Transcutaneous Electrical Nerve Stimulation) ultrasound devices, and the list is growing. Smart Systems could do much to customise multiple approaches, to produce multi-purpose instruments, to allow sensitisation to the particular needs of patients, and to pre-process, or even act upon, real-time information. Local action will reduce the need for interventions by remote parties, including service technicians, whilst data pre-processing, based upon multiple sensing, will reduce false alarms and also the amount of data that needs to be assimilated at the remote location.
- New concepts in wireless wearable sensors will facilitate chronic use, communicating through local Smart Systems as a gateway to wider networks (e.g.: Electronic Tattoos patch, chip on flexible support).
- Furthermore, telemedicine and healthy living systems will be supported by smart phones, which will favour the development of their use in remote areas, far improving the availability of medical expertise.

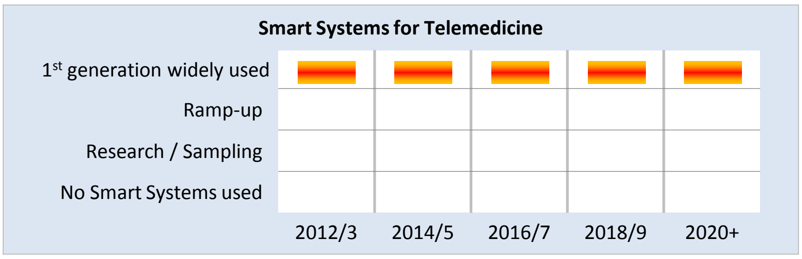
Multiple facets of telemedicine - *Sorin*

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

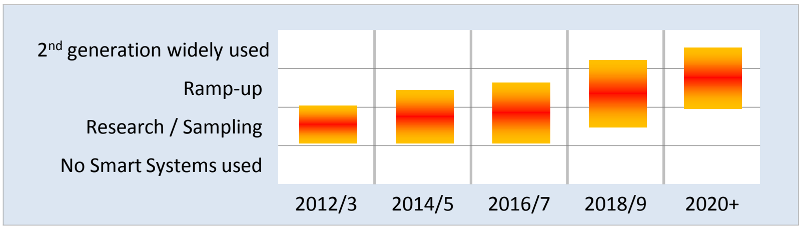
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Personal alarms for emergency and falls are in wide use.



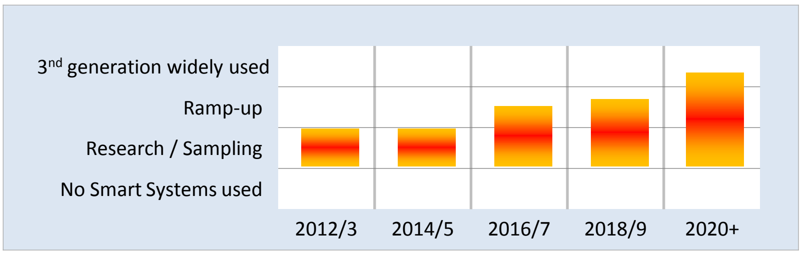
2nd generation Smart Systems are predictive and self-learning.

Reliable, predictive detection of the high risk of fall of a person at risk could trigger an emergency visit before the event.



3rd generation Smart Systems simulate human perception/cognition.

Remote real-time analysis of an active implanted neurological device directly monitoring a patient’s brain function, through a Brain Computer Interface.

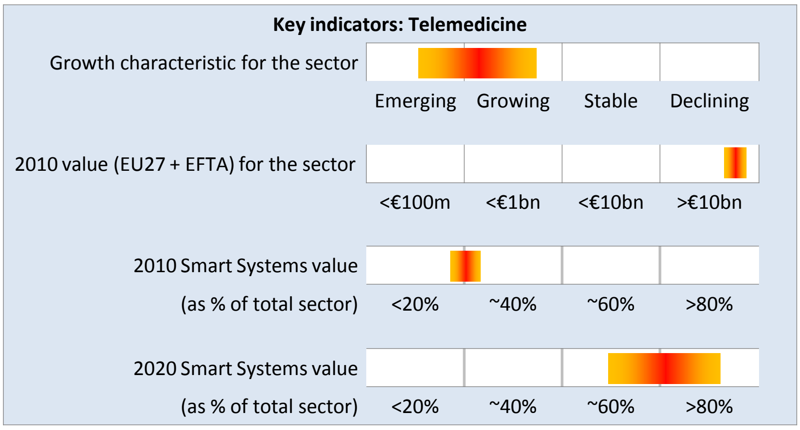


Sector forecast

The growth of telemedicine is inevitably linked to the Internet, smart phones and the Internet of Things. Smart phone culture itself is predicted to grow 24% worldwide between 2011 and 2015.

The potential for connected health devices is high: 25 million people with obstructive sleep apnea, 5.3 million children display Attention Deficit-Hyperactivity Disorder. These two afflictions alone will draw significant benefit of remote smart monitoring.

Remote patient monitoring is estimated to grow from $7.1bn in 2010 to $22.2bnn in 2015 (Kalorama, 2011). However, the global business opportunity will be closed to EU companies unless they can rapidly commercialise Smart Systems by using business models specifically aligned to exploit this technology.



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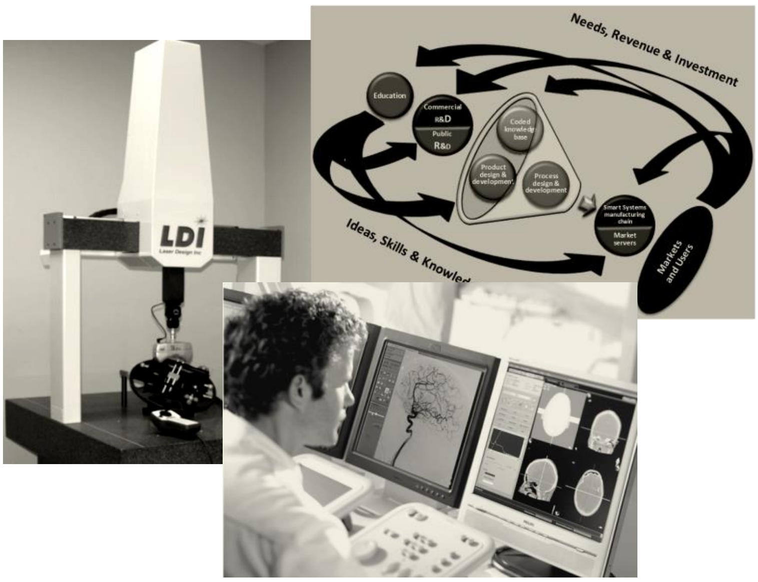
Quick links:

Sector overview | Diagnosis & Monitoring | Treatment & Surgical | In Vitro Processes | Implants | Telemedicine | EU Strengths & Research priorities

SMART SYSTEMS FOR MANUFACTURING / FACTORY AUTOMATION

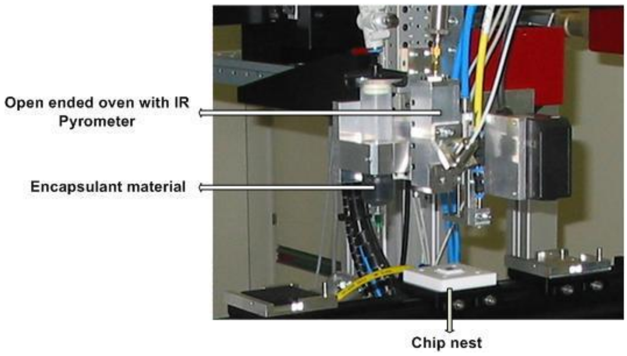


Smart Systems for Manufacturing / Factory Automation

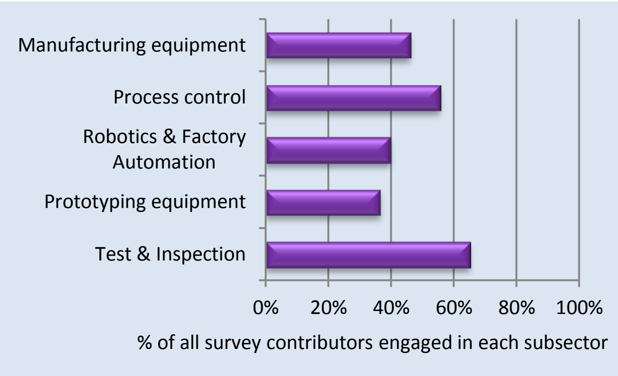
Overview

Smart Systems in Manufacturing promise to carry out local optimization underpinned by local knowledge bases, ranging from the examination of raw materials and parts and predicting subsequent machine settings to compensate for variation, all the way through to optimizing manufacturing parameters based upon end-product performance.

Smart Systems could in principle compensate from measurements on-line, at end-of-line or indeed from live data collected in the field as the product is used.



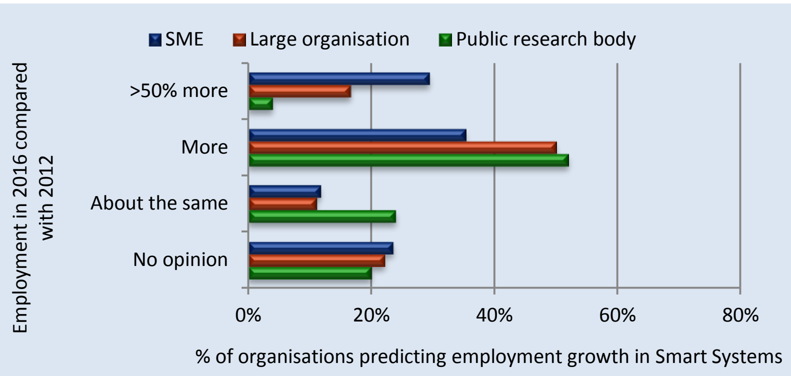
Frequency Agile Microwave Bonding System
Heriot-Watt University



Profile of subsectors

In the IRISS 2012 survey, 63 Smart Systems providers, representing the supply chain from research through to market servers, showed a relatively even engagement between subsectors, with a slight emphasis upon Test & Inspection (illustrated left).

The growing integration of test and inspection as an on-line process rather than an end-of-line procedure will infiltrate Smart Systems into the factory.



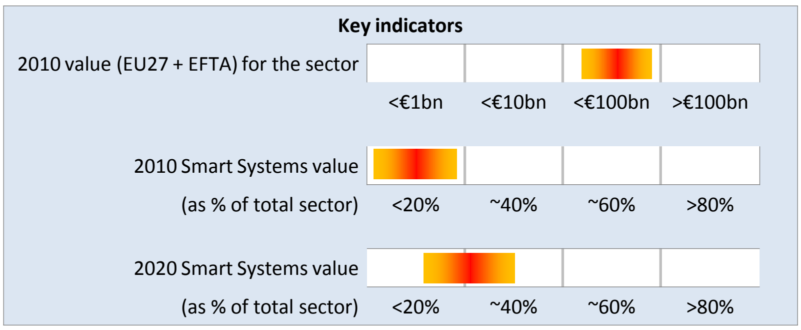
Growth prospects: Organisations

Of the Smart Systems providers surveyed, the great majority forecast employment growth, with a significant proportion of companies, particularly SMEs, predicting headcount increasing by more than 50% by 2016 (illustrated left). There were no predictions of reductions in headcount.

A similar picture emerged for growth in financial terms.

Growth prospects: Whole sector

The Manufacturing Equipment sector in EU27 + EFTA is immense in value, >€57bn. Currently, Smart Systems account for possibly ~10% of this, in machine automation, but could rise to ~20%, maybe >€12bn, by 2020 through wider adoption of smart technologies in each of the subsectors examined.



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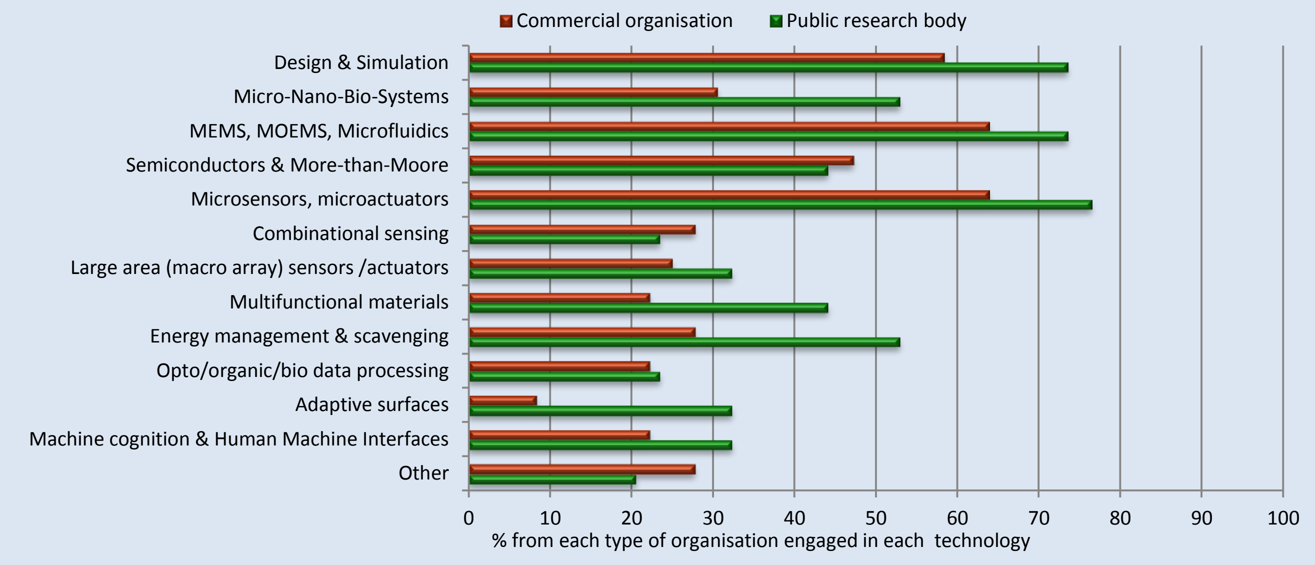
Underlying technologies



The front-running technologies reported by Manufacturing / Factory automation companies were respectively: Microsensors & Microactuators, MEMS, MOEMS and Microfluidics, Design & Simulation, and Semiconductors & More-than-Moore technologies.

Engagement by industry and public research bodies in Combinational sensing and Machine Cognition & Human Machine Interfaces both appeared relatively infrequently in survey returns. This is surprising considering the potential advantages of these topics in manufacturing processes and robotics.

Key issues for support action should therefore include:

- Combinational sensing for on-line process control
- Machine Cognition & Human Machine Interfaces for factory automation and robotics

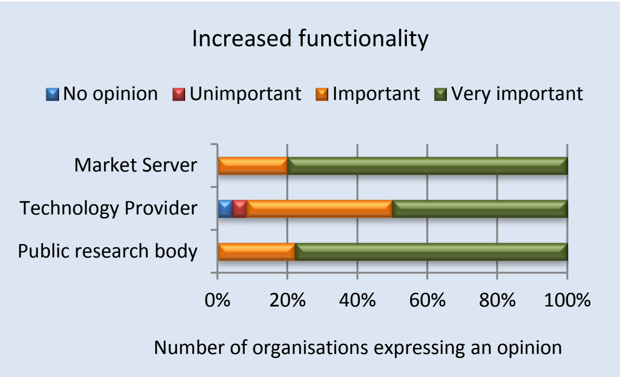
Drivers and barriers

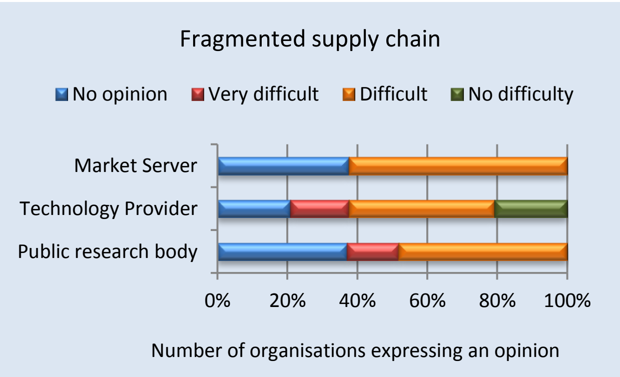
The survey of Smart Systems providers to the Manufacturing / Factory automation sector rated “Increased Functionality” as the most important driver compared to, in descending order, Reduced Cost, Increased Reliability, Global Competitiveness, New Markets, Simplicity in Use, and legislative drives to compel the use of new devices or techniques.

The most obstructive difficulty reported was “Fragmented supply chain”. Furthermore, responses were indicating that some 30% of public research bodies had no opinion about supply chain matters.

Accordingly, action should be considered to

- Encourage cooperation between companies and company clusters active in different segments of the supply chain, to work towards a streamlined and seamless Smart Systems supply chain.
- Encourage researchers to increase their interaction with and gain better understanding of the Smart Systems supply chain to achieve a better match between research approaches and manufacturing capability.





The sector and its subsectors

A typical manufacturing activity spans from design to delivery. Incoming raw materials and subassemblies are converted by production processes into tested end products, or part-finished items further up the product hierarchy (for example an aircraft wing, which is not an end product in itself).

Essential ancillary activities to the production line itself are the logistics of materials, parts and energy supplies, the management of waste and effluent, and a planning process that orchestrates the elements of the process, the just-in-time provisions of suppliers, and the delivery schedules of customers.

This chapter focuses upon the following subsectors:

- Manufacturing equipment
- Process control
- Robotics & Factory automation
- Prototyping equipment
- Test & Inspection

Each has differing requirements for Smart Systems.

Benefits of Smart Systems

The controlling inputs to a modern production line are data sets from CAD systems that generate tooling, manufacturing procedures and machine settings, and production planning systems that manage the flow of items appropriately according to the availability of raw materials, the varying requirements of different customers, and the reduction of waste and dead time.

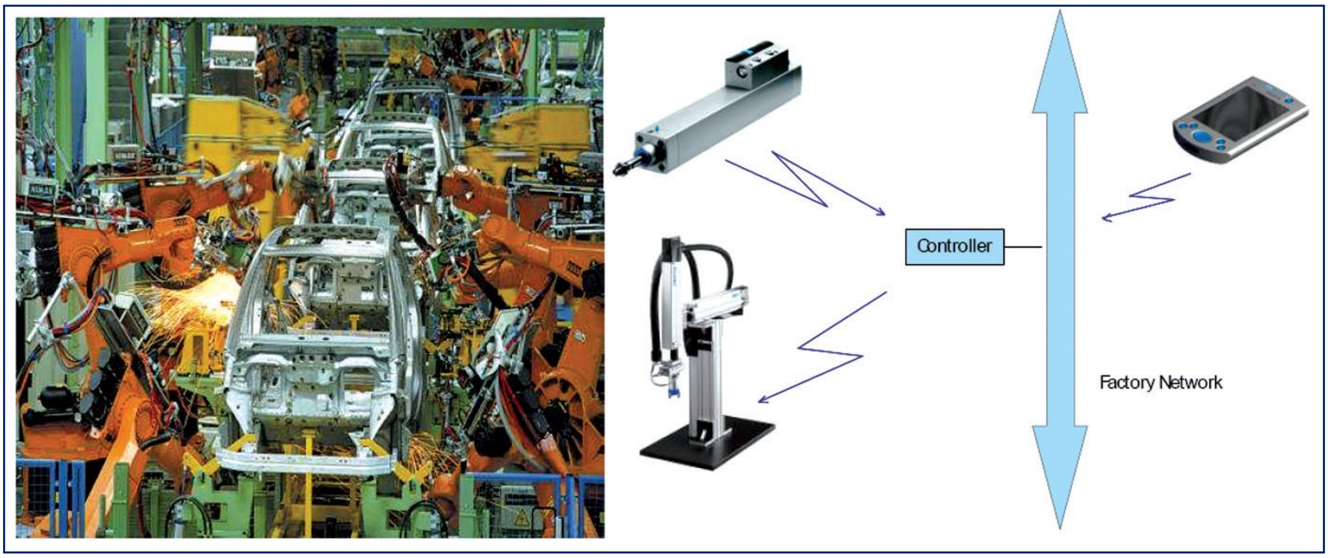
Current factory automation rests with well-developed control algorithms, which can only be effective when fed back with observations from the reality of on-machine sensors, human reporting and the statistical analysis of test results at the various stages of production, which culminate not just in final test but also upon customer acceptance procedures.

Today's on-machine sensors and in-line and end-of-line test equipment share fairly-well developed standard data interfaces but tend to present compromises in terms of their physical integration into the production line itself. Moreover, these sensing and testing activities "know" nothing of the finesse of manufacturing, nor the intricacies of the application of the end product, but simply send measurements to the factory management system.

Accordingly, the opportunity to "smarten" factory automation is clear:

- Miniaturised smart sensors can be installed intimately with processes, making minute adjustments through integrated actuators, not just as a result of local measurements, but through information networked from other smart systems throughout the production process.
- Smart tooling - for example cutting tools with in-built temperature and wear sensors – will not only increase yields by reducing damage and maintaining tolerances, it will also provide forensic traceability in the manufacture of critical parts.
- Smart processes might also interact with the products that they produce, opening the path towards products that themselves play a part in optimising the use of manufacturing materials and energy used in their production.

  They will optimise the route through manufacture and onward through logistics systems to the customer, ultimately eliminating manufacturing disruption and uncertainty, and accelerating the pace of the economy.



Wireless network of sensors for use in industrial processes

Technical Challenges

Integrated Smart Systems by definition take advantage of miniaturization and physical effects in the micro- nano- bio- and photo- domains. They are therefore an ideal vehicle to introduce developments from the first 5 KETs (Micro- Nano- electronics, Advanced materials, Nanotechnology, Photonics, Biotechnology) into the 6th KET: Advanced Manufacturing.

This does not necessarily mean that the introduction of Smart Systems into Manufacturing is dependent upon the progress in the KETs. There are strong opportunities for existing Smart Systems in manufacturing; but there needs to be a will to explore the "integration space" between Smart Systems and established manufacturing processes.

The fears of producing faulty goods, product recalls and harm to customers do make manufacturers wary about introducing process changes. There are therefore good technical prospects to learn from the successful implementation of safety-critical Smart Systems in healthcare, automotive, and aerospace sectors.

Societal Challenges

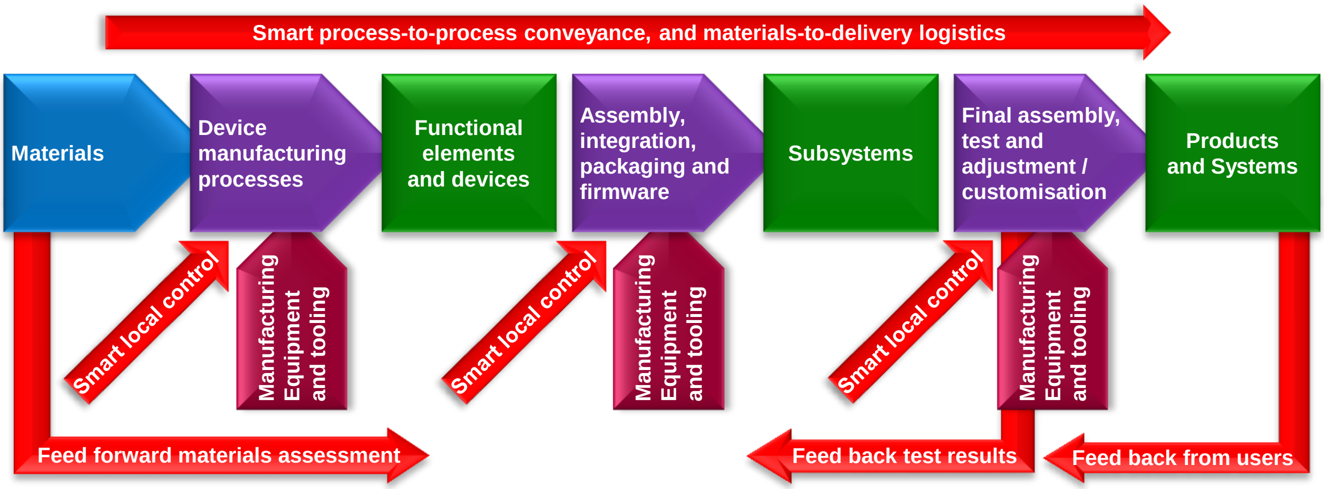
As with all automation and efficiency drives there are societal consequences for the introduction Smart Systems into Advanced Manufacturing:

- A reduction in the need for skilled labour, which may go against political targets for education and employment.
- Easy global replication of Smart Systems benefits and the intellectual property gathered in their Knowledge Bases.

Both threats warrant attention. The question of jobs vs votes is not easy to resolve; hence the need for industrial strategies that accelerate manufacturing growth, and the production of competitive products with a gestation period that keeps them ahead of their rivals.

The insidious "leakage" of knowledge is also something that needs to be addressed in a strongly-connected world.

Introduction of Smart Systems into Manufacturing



Applied to manufacturing, Smart Systems can interact with processes locally by analyzing one or more attributes of each process and applying the rules of a Knowledge Base to optimise or correct as necessary.

Through their inherent robustness and capability to recalibrate over time, Smart Systems for Manufacturing are ideally suited to unattended operation and to operation in environments hazardous to humans or which may be contaminated by the presence of humans – "the air-free factory"

- Human-free manufacturing is a necessity in semiconductor production. Agile Smart Systems will allow the migration of this concept to manufacture in other sectors – notably in Healthcare and in the production of Electric Vehicle and Aerospace battery packs

European position

Europe hosts a manufacturing base that builds its strength on a long-established engineering tradition, a strong R&D capacity and universities, the ability of industry to adapt to technological progress, and to produce high quality products that satisfy customers all around the globe.

Europe is homeland to major manufacturing industries (for example communication industries, electronics, energy, chemical, transport and construction, food and beverage processing, etc) which utilize this position to maintain competitive and profitable business throughout the EU and the world.

According to the i2010 Mid Term Report (2008, i2010 EU policy framework of DG-INFSO), manufacturing is the driving force of Europe's economy, contributing over €6,553bn in GDP and providing more than 30 million jobs. It covers more than 25 different industrial sectors, largely dominated by SMEs, and generates annually over €1,535bn worth of value added services.

Smart Systems technology will help European manufacturers to maintain and increase market share and profit margins in the face of increasing competition from low-cost regions of the world.

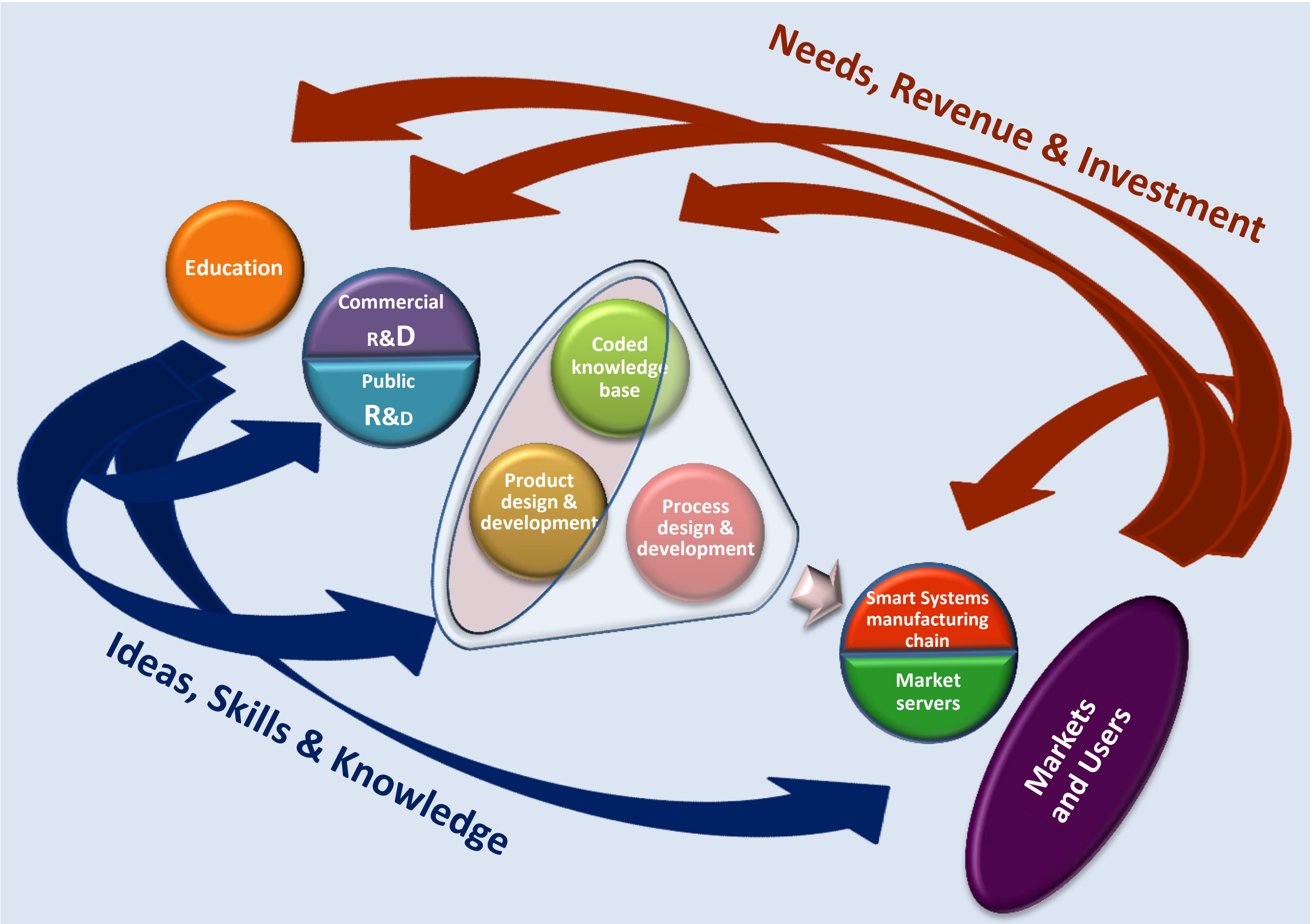
One step towards this would be to:

- Providing access, especially for first time users of Smart Systems, to pilot experimental production lines upon which to observe the productivity enhancements shown by Smart Systems in manufacturing, and to assess their reliability in terms of manufacturing up-time and in terms of product consistency

Beyond technology:

- Strengthening the ecosystem of the supply chain within Europe will help the large European ORMs and system integration companies to retain their R&D operations within Europe.
- Maintaining company's R&D focus in Europe will sustain their research relationships with universities and other RTOs, with a concomitant fertilisation of education, and the attraction and training of the vital next generations of designers, engineers and scientists

Manufacturing within a European ecosystem for Smart Systems



Smart Systems for Manufacturing / Factory Automation: EU Strengths & Research priorities

Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Sector as a whole	• A good installed base especially in high technology manufacturing, already benefiting from the use of Smart Systems and open for further improvement	• Current Smart Systems largely focus on operator simplicity, rather than tackling the more difficult demands of sensing the immediate activity where tools interact with products	• Exploit synergies between manufacturing sectors, so that the experiences of early adopters of Smart Systems can be applied more widely	• Accumulating manufacturing knowledge within Smart Systems makes it easy to transport to competing regions
Manufacturing equipment	• Good high precision engineering manufacturing base, closely situated to gather the user experience necessary for Smart Systems development	• Some reluctance to adopt autonomous automation, as the risks of worker injury or unexpected product defects may be perceived as high	• Migrate fail-safe smart approaches from other sectors (We trust mass transit) • Migrate the people-free semiconductor factory to other processes	
Process control	• Head start of process control experience		• Explore niches, such as oil exploration, which process control could learn from	• New processes do not necessarily depend on historic knowledge
Robotics / factory automation	• Smart Systems knowledge resides in major EU-based factory automation players	• Technology adoption difficult because of cost	• Distributed Smart Systems between human workers and robotic co-workers	• US and Japan gaining an early technology position
Prototyping equipment	• Good continuity of fine engineering skills in some EU countries • Culture of specialisation		• “Craft culture” in some regions could become a “Smart culture” • Recognise “Product hacking” as a potential mass market	
Test & Inspection	• Good standards and standards organisations and a large industrial base developing, marketing and using test & inspection	• Inspection for mixed technologies/materials and large spans of scale from nano- to macro- not yet available	• Capitalise upon spin outs from, for example, Aerospace and CERN • On-line and in-line inspection for critical products; food; medicine	

Sub-sector	Priority actions	Longer term actions
Sector as a whole	• Develop Smart interfaces and smart plug & play modularisation of the manufacturing process, to encourage step by step introduction of factory automation • Exploit synergies between manufacturing sectors, so that the experiences of early adopters of Smart Systems can be applied more widely	• Migrate the low-contamination semiconductor factory to other processes
Manufacturing equipment	• Real-time on-line and in-line sensing and control	• Standards for machine-to-machine optimisation, sharing measurements, not just controls
Process control	• Identifying and recording human expertise and “x factors” for integration into smart systems	
Robotics / factory automation	• Interfaces between robots, their human and other robotic co-workers and their work environment • Smart combinational sensing (robot haptics) • Interaction with ubiquitous mobile devices	
Prototyping equipment	• Continuity between prototyping and production, through smart monitoring of the models, capturing all the experience learned from making and using the prototype • Developing strong links from design to simulation to prototyping, and vice-versa	
Test & Inspection	• Connect to internet of things – raw materials all the way to field (use) reports	

Quick links:

Sector overview | Manufacturing equipment | Process control | Robotics / factory automation | Prototyping equipment | Test & Inspection

Manufacturing equipment

Overview

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Today's on-machine sensors and "in-line" and "end-of-line" test equipments share fairly-well developed standard data interfaces but tend to present compromises in terms of their physical integration into the production line.

Opportunities for Smart Systems

- Distributed intelligence and smartness will allow more flexibility for product changes, customisation and optimization.
- Intimate control of the process micro-environment will aid product yields and consistency.
- Smart tooling could adjust for material variations and wear, and may collect process information.

Hurdles to be overcome

- Fears of producing faulty goods, product recalls and harm to customers do make manufacturers wary about introducing process changes.
- Mastering the ability to communicate and clusterise
- Standardisation of interfaces with intelligent tooling subsystems.
- Integration of, and with, test and measurement systems.

Applications

- Profiting from the experience of microelectronics, embedded miniaturised sensors can be used to log operational parameters, allowing off-line or on-line quality control and improvement of the overall process.
- Smart tools can optimise lifetime of tools and reduce dead time of machines, and can realise compensation for materials and operational conditions, allowing higher production throughput and/or quality to be reached.
- Smart control can optimise the overall process of individual machines locally, and contribute to overall production line optimisation
- Health and Usage Monitoring can help predict service intervals and machine/tool changes, reducing incidents and downtime, and increasing overall throughput and quality.
- Smart machines can improve the communications with the human operators and co-workers.

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

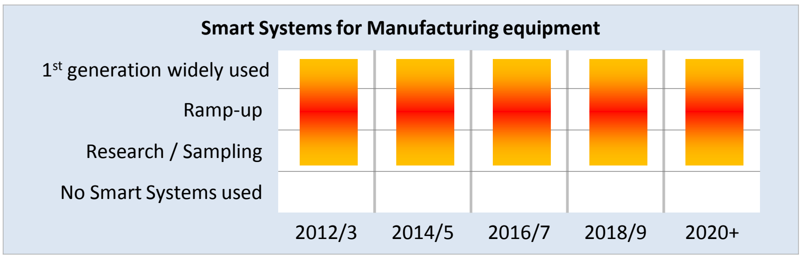
Placement machines equipped with vision and pattern recognition systems so that they can align parts for assembly.

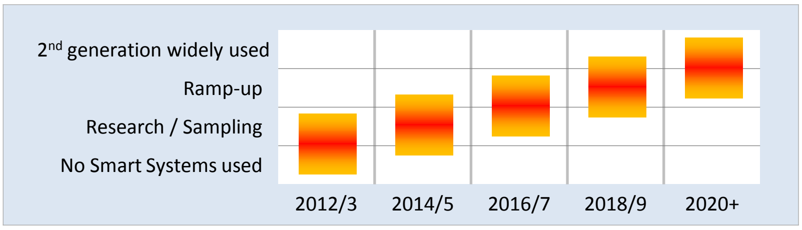
2nd generation Smart Systems are predictive and self-learning.

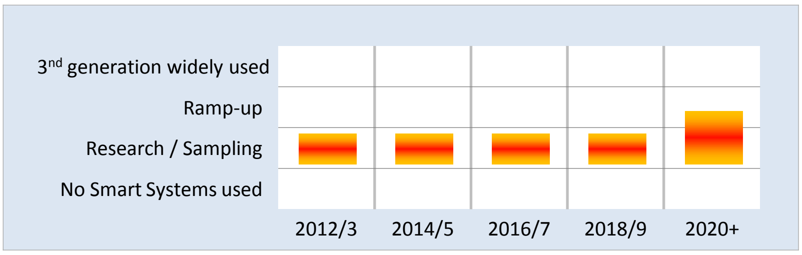
A process line that can analyse variations in raw materials and rapidly change parameters based upon prior experience..

3rd generation Smart Systems simulate human perception/cognition.

A machine instructed to detect imperfections and make repairs to wooden shelves and beams.







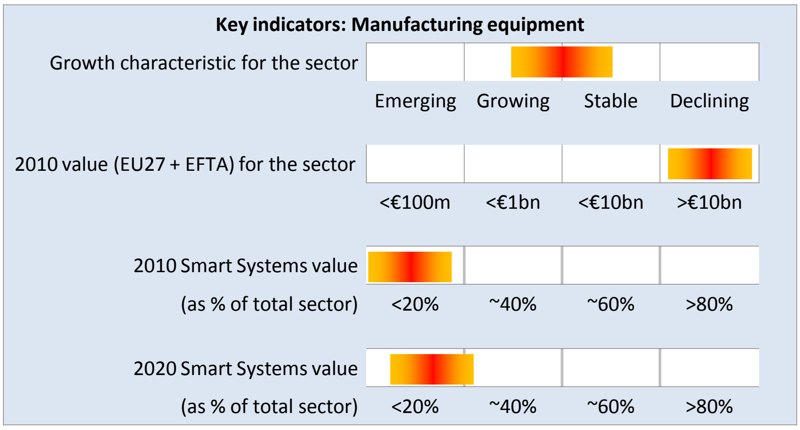
Sector forecast

Europe currently accounts for about 31% of manufacturing value worldwide (down from 50 %; Source: Eurostat).

Manufacturing equipment covers a large domain of related subareas, where the total market is the sum of all of these.

Examples of some manufacturing equipment subareas:

- Semiconductors, the European share has increased to 24% corresponding to about €7bn (source: SEMI)
- The European packaging machinery market is predicted to reach €10bn in 2013, with a 3% growth rate (source: Frost & Sullivan)



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Quick links:

Sector overview | Manufacturing equipment | Process control | Robotics / factory automation | Prototyping equipment | Test & Inspection | EU Strengths & Research priorities

Process control

Overview

Process control covers control of batch and continuous processes for the production of parts and substances ranging from petrochemical to food and beverages, where products may be discrete as well as continuous (solid, liquid, gaseous).

Process conditions range from potential safety hazards to extreme quality sensitivity. An example of the latter is the delicacy of taste and smell in the perceived quality of food products.

Changing a production process may be a costly and potentially risky intervention, and may not immediately result in meeting the volume, cost sand quality objectives targeted.

Opportunities for Smart Systems

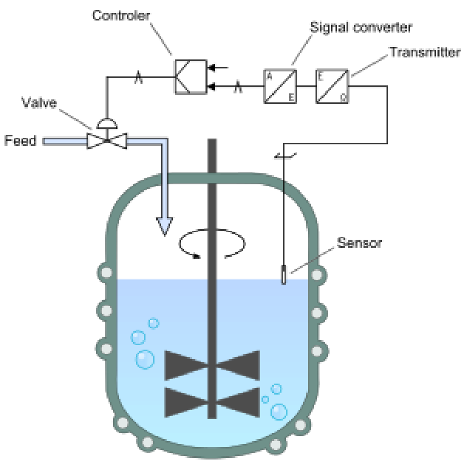
- Adapting to changes in conditions, products and materials. Plug-in process steps (Plug & play).
- Smart Systems may contribute to achieving the aim for zero incidents and defects, reduced overall risks, and without 100% screening.

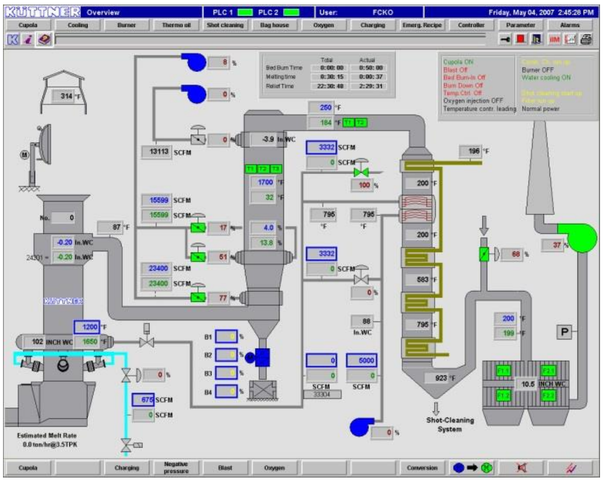
Hurdles to be overcome

- Two main difficulties: Stability (of closed control loops; testing (prediction of hazardous breakdown).
- Need to capture the knowledge of the analogue world, while there exists a danger of introducing digital approximations and artefacts.
- For food and beverages, the need to measure parameters representing or best approximating human quality perspectives, such as texture, taste and smell

Applications

- Process control already has immense computer power and connection to production lines. Intelligent sensors and actuators – used in proximity to the products being made, or even embed in those products.......
- The introduction of Smart Systems allows an increase of the intelligence of the system in a distributed fashion, and thereby allowing local optimisation of the process, and reducing risks by enforcing locally safe operating limits.
- Smart production processes may result in a significant reduction in energy consumption and waste of valuable resources, including precious and rare materials.
- Smart production processes will allow automatic adaptation to differences in raw materials and conditions, which in particular for the production of food and beverages would results in a more constant / less varying quality and less waste.





Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

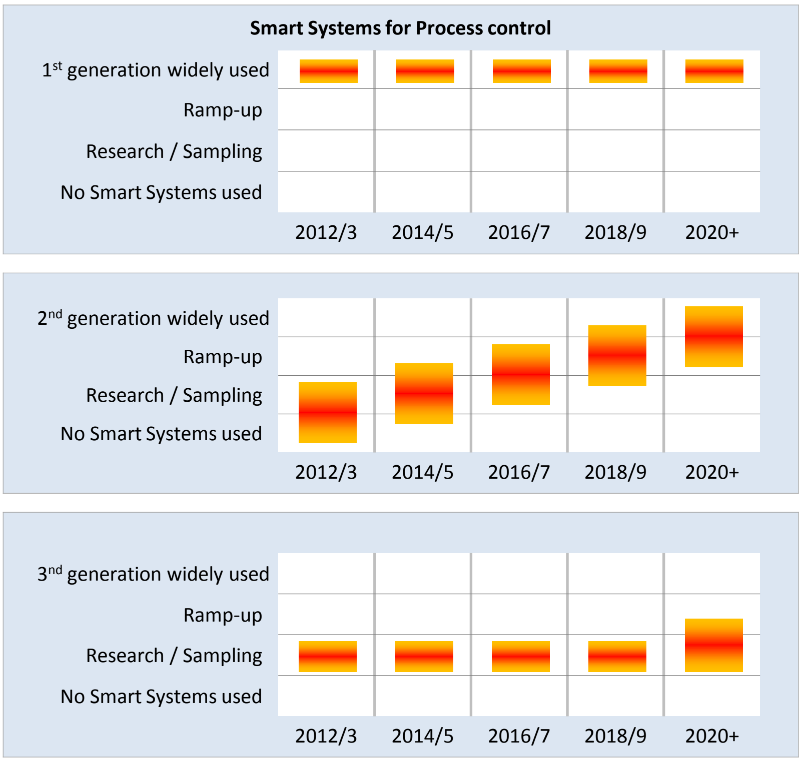
Health and Usage Monitoring and Smart Data loggers at point of application, and automated manufacturing systems are current examples.

2nd generation Smart Systems are predictive and self-learning.

Improvement of process measurements by smart probes. "Conservative" manufacturing will adopt 2nd generation systems only after adoption in other sectors.

3rd generation Smart Systems simulate human perception/cognition.

Conservatism – safety and product recall risks – will delay 3rd generation use until fully proved – unless essential for a product, material or new paradigm.

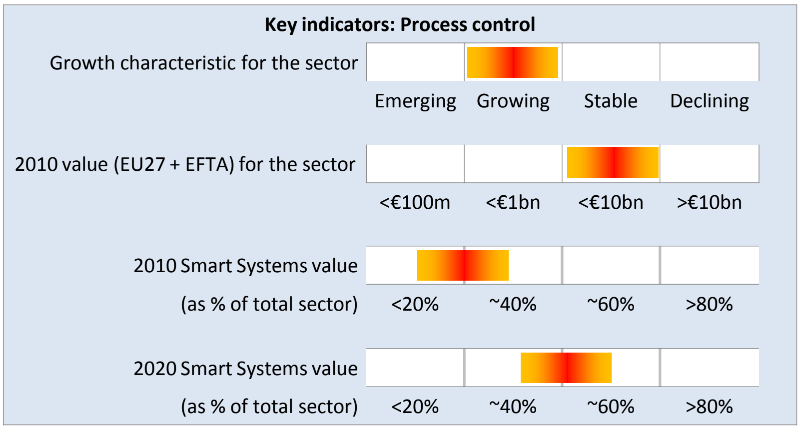


Sector forecast

Process control covers a large domain of related subareas, where the total market is the sum of all of these.

Examples of some subareas:

- The world wide Distributed Control Systems market is predicted to reach €11.2bn in 2013 with a share for Europe of about 30%, depending on whether subsidiaries of European companies are counted. (source: Frost & Sullivan)
- The Automation and Control market in the Oil & Gas Industries is predicted to reach €1.3bn for Europe in 2013. (source: Frost & Sullivan)



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Quick links:

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Robotics / Factory Automation

Overview

This sector in practice covers several sub-areas:

- Manufacturing robots
- Manufacturing robotics
- Factory automation

Many *of* today's *manufacturing robots* could still be considered as manufacturing equipment, but over time will converge with manufacturing robotics.

Factory automation is the physical progression/ connection between machines/process steps (process steps maybe within a machine).

Opportunities for Smart Systems

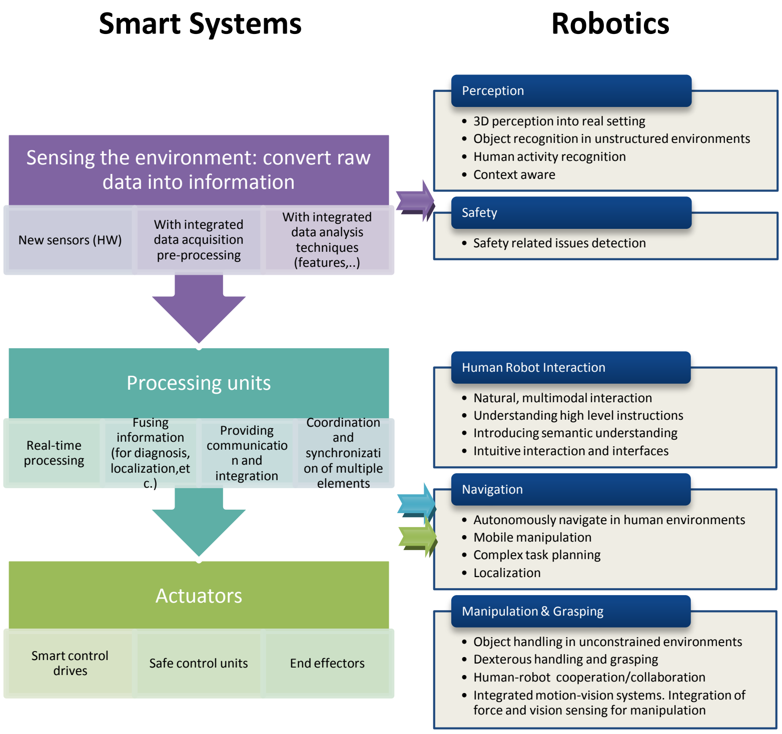
Integrated Smart Systems, through their miniaturisation and inherent robustness, can be tailored to fit intimately into the materials flow throughout the production line, fine-tuning the ' 'micro-environments' that envelop the product at every stage of manufacturing.

Hurdles to be overcome

- A manufacturing line has to be specifically designed for automated/robot/robotised machines. Unless a modular approach can be devised for a step by step introduction, a significant initial investment and production downtime will occur.
- The cooperation intelligent machines with human and also robotic co-workers has to be improved.

Applications

- Robotics / Factory Automation has the potential for high quality, flexible manufacturing with optimised resource management and at contained costs.
- Robotics / Factory Automation allow an optimum distribution of tasks between human and robotic co-workers
- Robotics / Factory Automation can contribute significantly to European based production staying competitive



Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

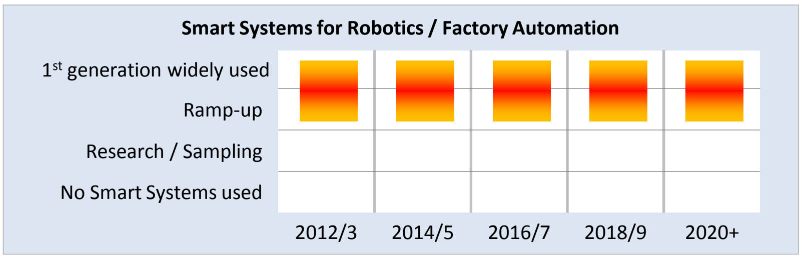
For example, a manipulator arm, programmed to put one type of bolt into an engine block with a specified force, and verifying the result.

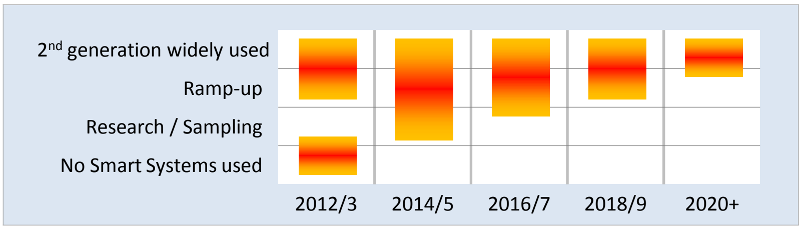
2nd generation Smart Systems are predictive and self-learning.

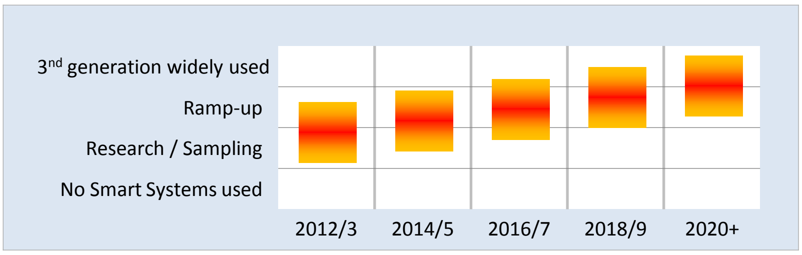
A manipulator arm, instructed to put several types of bolts into an engine block each with a specified force, self-learning the process to execute this efficiently.

3rd generation Smart Systems simulate human perception/cognition.

Robotic co-workers, that can work with, or in the presence of humans.



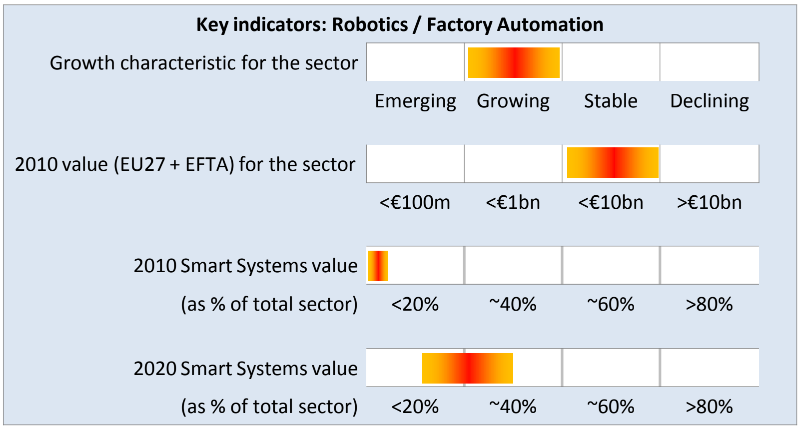




Sector forecast

Robotics and factory automation cover many related subareas, where the total market is the sum of all of these.

- The subarea Automated Materials Handling equipment in Europe reached about €2.51bn in 2007 with a growth rate of about 3.4% (source: Frost & Sullivan)
- The subarea Welding Robots in Europe is predicted to reach about €310m in 2013 with a growth rate of about 11% (source: Frost & Sullivan)
- The subarea Plant Asset Management in Europe is predicted to reach about €370m in 2013 with a growth rate of about 7.7% (source: Frost & Sullivan)



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Quick links:

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Prototyping equipment

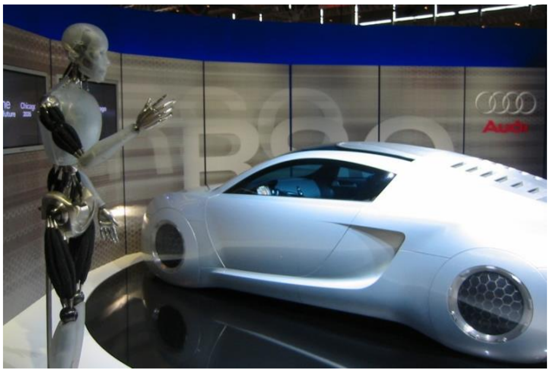
Overview

"Prototyping" might be used for (1) Validating aspects of a design (2) Preproduction to check items before serial manufacture (3) Flexible small batch (even batch of one) "direct manufacturing", including potentially manufacture at the place of use.

The equipment used can range from hand tools, through scaled-down and simplified production methods, and ultimately to revolutionary 3D printing.

Opportunities for Smart Systems

- Smart sensors built into the prototype itself can evaluate it and help judge its conformance to eventual series production.
- Smart prototyping equipment can record the parameters used in the manufacture of a product model
- Smartness can provide "skill" to fill in specification gaps and to augment the abilities of users who may be unfamiliar with new processes and the new products resulting from their use.



The "I Robot" film car was made from an Audi with rapid prototyping industrial KUKA robots - *Eirik Newth*

Hurdles to be overcome

- Additive technologies, such as 3D printing, can prototype parts, but not systems
- Use of multi-materials to make multifunctional products
- Need to extrapolate prototype performance to whole-life performance

Applications

Direct manufacturing and Rapid prototyping differ from typical mass-manufacture processes in that they are typically software driven, with no physical tooling. 3D printing and stereolithography, are two example processes, but others are emerging, including one novel process where materials are sculpted under the influence of electric fields.

- Direct manufacturing ("tool-free manufacturing") allows for "batch of one" product customisation
- Rapid prototyping allows for the production of (life-size, upscaled or downscaled) models to illustrate and trial/review one, some or all aspects of a product that is subsequently to be manufactured using more economical series manufacturing processes

The processes used may typically be slow, but the timescales and up-front costs are low, which can be over-riding considerations when just a few items are required or, as in the case of prototyping, multiple aspects of a product need to be examined, perhaps iteratively, as part of the design cycle.

A rapid prototyping machine using selective laser sintering
Photo: *Renato M.E. Sabbatini*

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

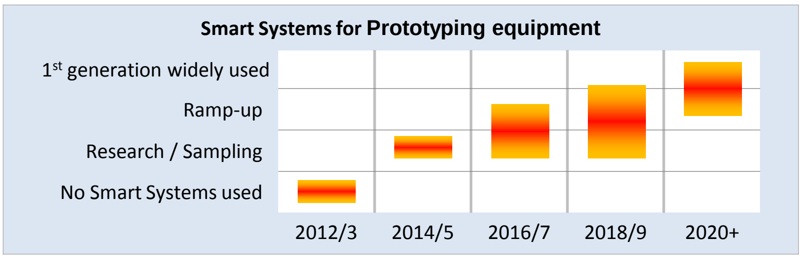
There are strong efforts in groups such as the RepRap project (founded at the University of Bath, UK, 2005) to arrive at “plug & play” processes.

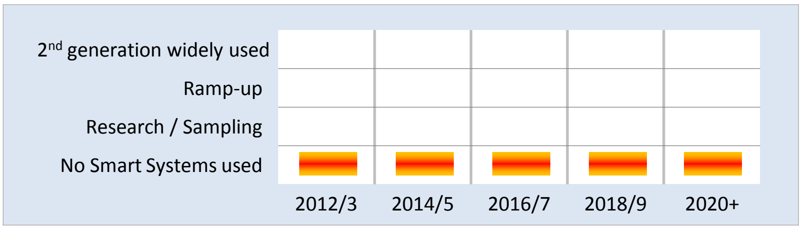
2nd generation Smart Systems are predictive and self-learning.

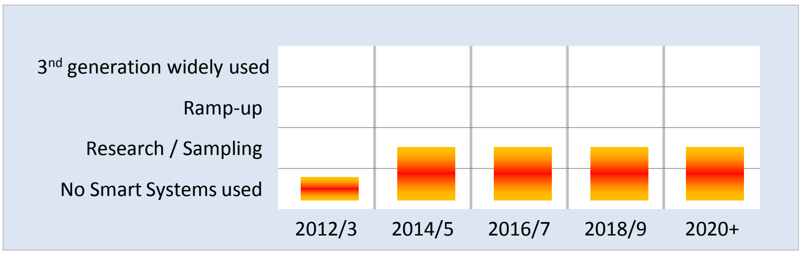
Due to the “batch of one” nature of prototyping, self-learning (as opposed to self-recording) systems are probably not useful.

3rd generation Smart Systems simulate human perception/cognition.

The Rapyuta database is part of the European Robo Earth project, started in 2011 with the hope of standardising the way robots perceive the human world – and to confront unusual situations.





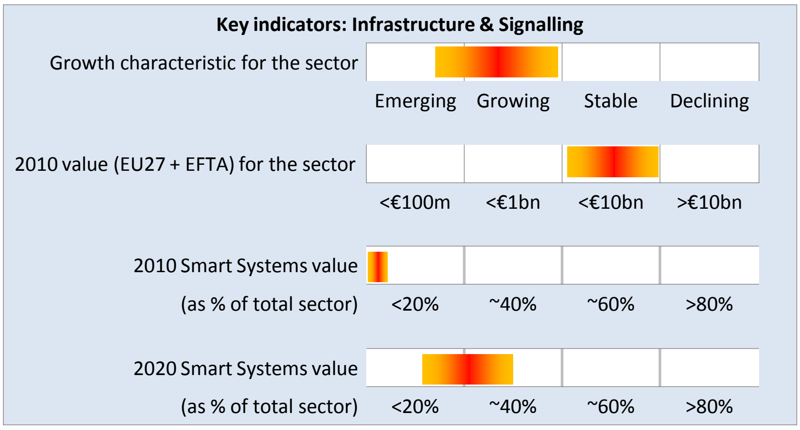


Sector forecast

As product life cycles continue to reduce, the use of smaller batch sizes, or the customisation of long-running products will grow dramatically.

The “Craft culture” in some regions and product sectors could become a “Smart culture”, building on the experience and business models of the glass and ceramic industries.

Furthermore, an emerging subculture of “product hacking” - the act of modifying or customizing everyday products to improve their functionality, repurpose them or just for fun - is growing (ref www.designboom.com). This promises to make everyone a designer, so there will be a mass demand for Smart Systems to provide the underlying skills needed to ensure that the resulting products will work.



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Quick links:

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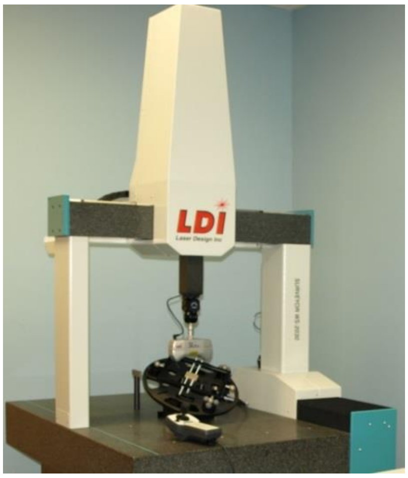
Test & Inspection



Overview

Test & inspection will take an ever more important place in manufacturing:

- to ensure error free operation of complex products, and thereby reduce non-quality costs
- to reduce manufacturing costs and waste

Test & inspection will evolve from today's mainly incoming and outgoing test & inspection by adding:

- in-line / in process test & inspection
- on-line test & inspection with process feedback

Opportunities for Smart Systems

- From off-line and laboratory instruments, smart sensors and procedures for in-line and on-line use.
- Multi-parameter sensors recognising target functions rather than simple thresholds.
- The qualification of highly-integrated products by non-intrusive methods at production line speeds
- Smart feedback to the production process.

Hurdles to be overcome

- Adaptation to and integration into production line and/or production machines.
- Adaptation to potentially hostile and aggressive production environments, and the consequences for calibration, accuracy, aging, drift, etc.
- Acceptance of in-line test & inspection as an alternative to end-of-line test & inspection for certification.
- Product / system / subsystem integrated test.

Applications

Advanced products pose tough questions in Test & inspection.

These questions spread further, to encompass the validation of tooling, the calibration and control of manufacturing processes, and the characterisation of multi-parameter sensors and actuators.

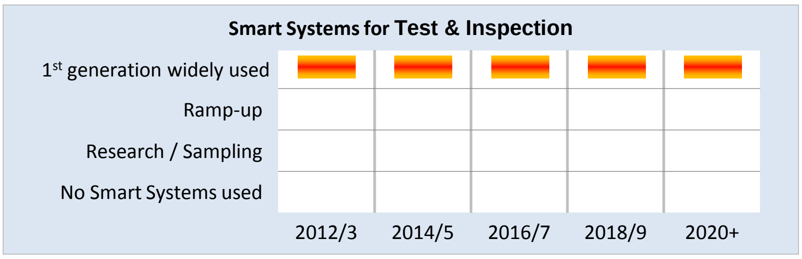
The advanced expertise of the test laboratory has not yet made it to the production environment, but it will be needed there. Smart, adaptive Test & Inspection must be integrated into every phase of design and manufacture.

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

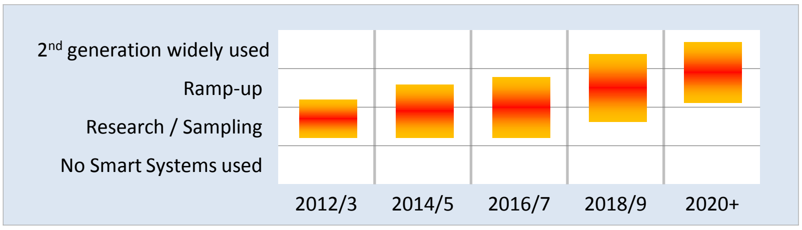
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

For example, a test system that can be programmed to autonomously perform tests and test sequences.



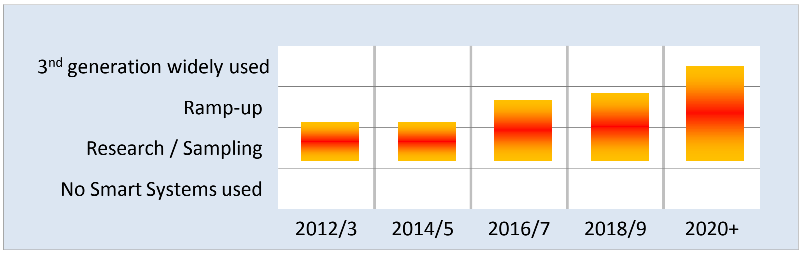
2nd generation Smart Systems are predictive and self-learning.

A test system that is self-learning and adapts tests and test sequences that it performs autonomously according to variations in the production process.



3rd generation Smart Systems simulate human perception/cognition.

A test system that autonomously decides on tests and test sequences, on variations and adaptations of tests as a function of the production process.

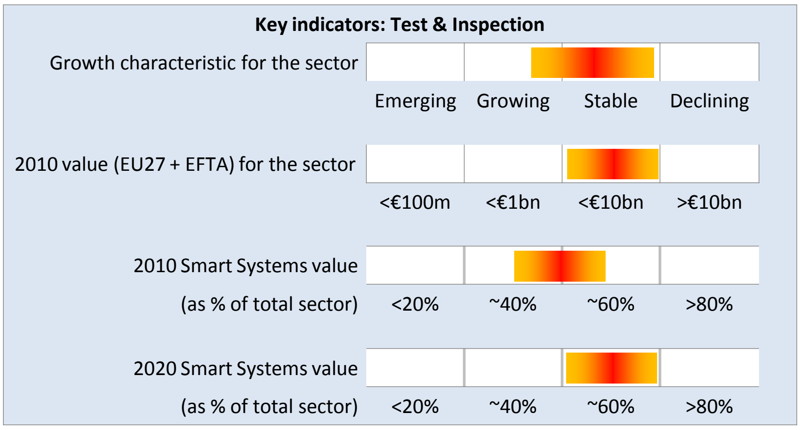


Sector forecast

Test & Inspection covers many related and product specific subareas, the total market being the sum of all of these. The subarea Non-Destructive Testing alone is forecasted for 2013 at about €1.23bn world-wide, for Europe €370m with a growth rate of about 7.2 % (source: Frost & Sullivan).

The Internet of Things will extend Test & Inspection to cover product lifetime:

- object and history tracing (via RFID) will connect embedded test / measurement facilities at different integration levels:
- systems level
- subsystems level
- parts / component level



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SMART SYSTEMS FOR COMMUNICATIONS

Smart Systems for Communications

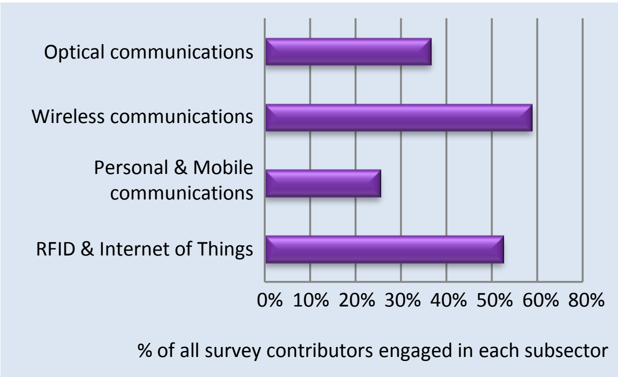
Overview

The capability for Smart Systems to communicate, with users and with other collaborating systems is paramount.

Furthermore, the individual elements of Smart Systems may be integrated wirelessly rather by than direct physical integration.

But, importantly, Smart Systems themselves are set to enable immense strides in the whole domain of Communications within a Connected World.

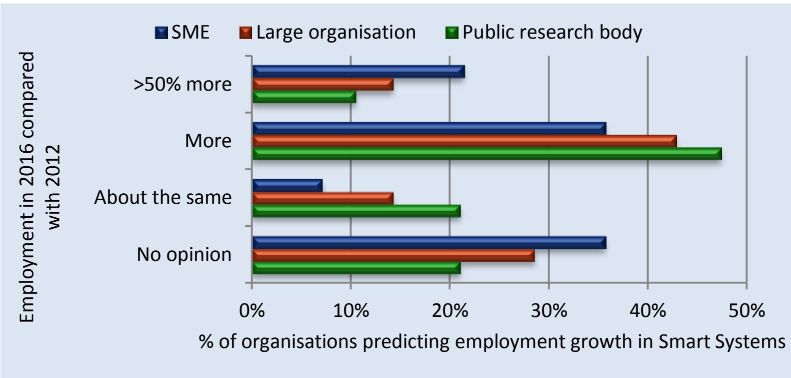
Smart cryptographic keyboard – *© Arts & Science*



Profile of subsectors

In the IRISS 2012 survey 51 Smart Systems providers, representing the supply chain from research through to market servers, revealed the distinctions between subsectors illustrated left.

“Wireless” technology may of course include “Personal & Mobile”, and is a prime requirement for RFID & the Internet of Things. Bearing this in mind, it is likely that all these subsectors merge to a great extent.



Growth prospects: Organisations

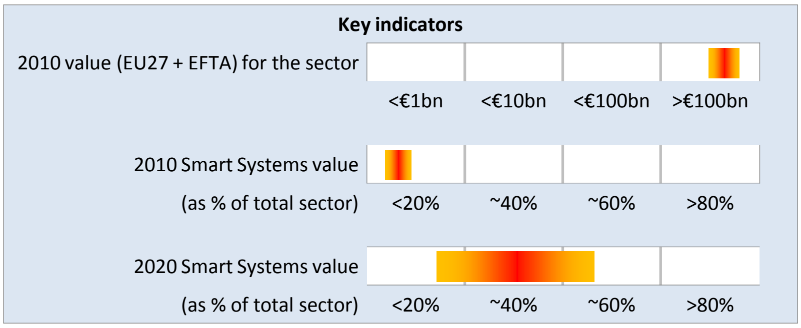
Of the Smart Systems providers surveyed, the great majority forecast employment growth, with a significant proportion of SMEs predicting headcount increasing by more than 50% by 2016 (illustrated left). There were no predictions of reductions in headcount.

A similar picture emerged for growth in financial terms.

Growth prospects: Whole sector

The Communications sector in EU27 + EFTA is immense in value (€660bn in 2010). Currently Smart Systems account for possibly 5% of this, but could rise to ~20% (€120bn) by 2020 through the greater adoption of secure solutions, of networked smart devices (for example smart meters) and the adoption of the Internet of Things.

Smart-phone usage - an enormously significant smart interface - will continue to rise rapidly in the years to come.



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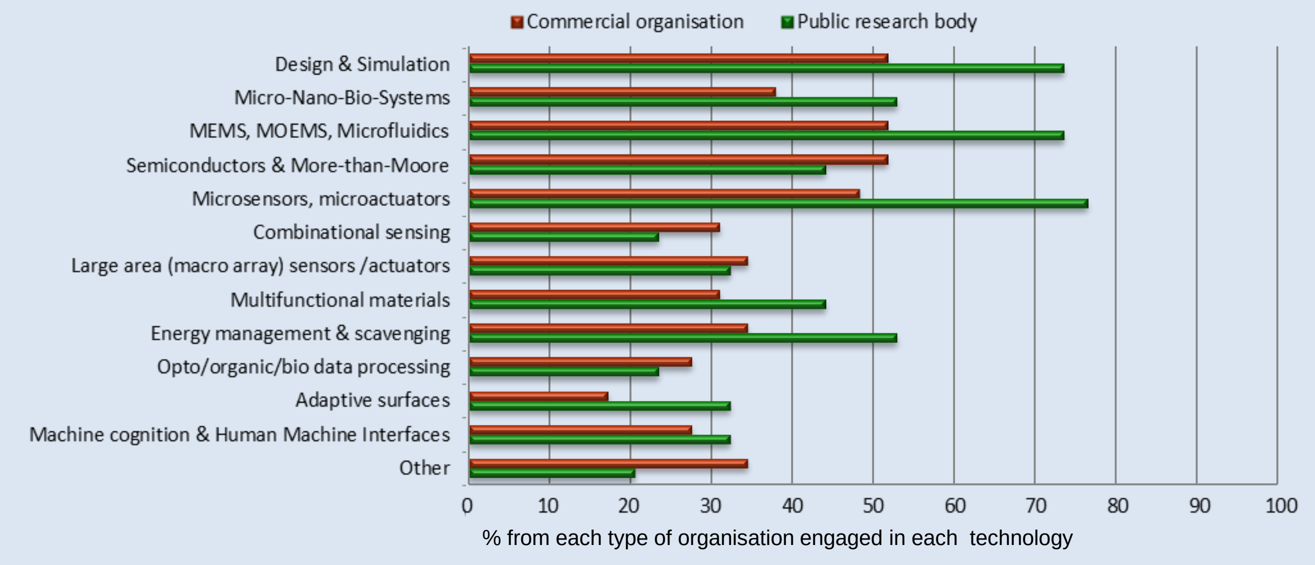
Underlying technologies



The three front-running technologies reported by communications companies were, with equal emphasis: Design & Simulation, MEMS and MOEMs, and Semiconductors & More-than-Moore technologies. Microsensors & Microactuators followed in popularity.

A high proportion of Public research bodies report undertakings in Energy management & Scavenging an in Multifunctional materials, which also seems to have penetrated rather less into commercial application than might be expected bearing in mind the requirements of the Internet of Things for portable and autonomous power supplies. A key issue for support action should therefore be:

- Strengthening the exploitation of Energy Management & Scavenging technologies
- Developing multi-functional materials to support the integration of the smart communications systems.

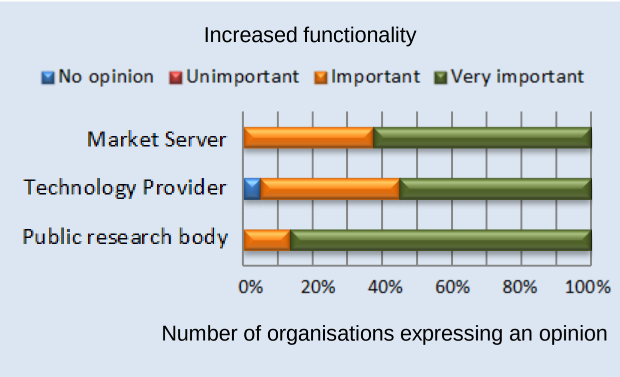
Drivers and barriers

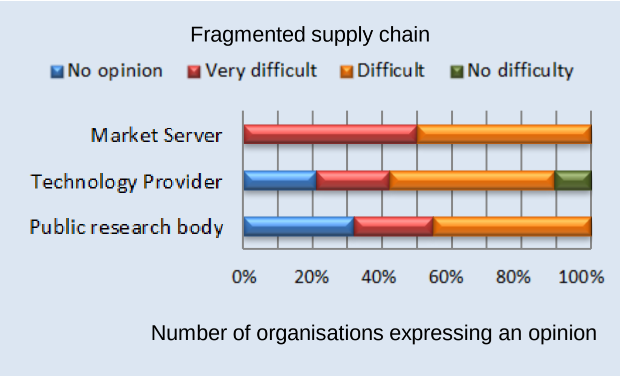
The survey of 51 organisations engaged in Smart Systems in relation to Communications & RFID rated "Increased Functionality" as the most important driver compared to, in descending order, Reduced Cost, Increased Reliability, Trusted execution, Global Competitiveness, New Markets, Legislative drives, and Simplicity in Use.

The most obstructive difficulty reported was "Fragmented supply chain", closely followed by "Skills shortages". Some 30% of public research bodies had no opinion about supply chain matters.

Accordingly, action should be considered to:

- Encourage researchers to gain better understanding of the Smart Systems in manufacturing and in supply chain to achieve a better match between research approaches and commercial needs
- Address skills shortages in communications technologies and related technologies particularly in the security and analogue domains





The sector and its subsectors

Towards the fully connected digital economy and society of the future, telecommunications is already playing an important role of supporting and controlling all the infrastructures needed for e-heath, e-mobility and e-transportation, smart grid, smart cities and the digital society in the cloud – and also in manufacturing, environmental monitoring, e-payment, and governmental services.

These global trends are mirrored in the four sub-sectors for Smart Systems:

- Personal and Mobile communications already rely upon smart phones and could extend to body area networks and ambient assisted living, although there are concerns about security and privacy protection.
- Connectivity - every sensor, every machine and eventually every object will communicate – for example through the upcoming Internet of Things.
- Optical communications are not only fuelling the higher data rate of national and international backbones, but also, at the other end of the scale, the new capabilities brought about by the admixture of silicon and photonics technologies.
- Wireless technology will play an increasing and significant role in the underlying communication infrastructure. Interfaces between humans and the infrastructure will be mainly through mobile and wireless devices (smart phones, tablets), and the Internet of Things. Machine-to-Machine communications will rely on wireless smart devices (for example sensors) to enable rapid, flexible and cost effective deployment.

The expansion of the Communications sector will depend upon:

- System availability and resilience in, particularly, the Wireless Communications infrastructure needed for broad coverage.
- Privacy, Security and Reliability need to be cornerstones for the European Digital Society.

Benefits of Smart Systems

Smart systems are key enablers to improve the quality of life for citizens through energy efficient ubiquitous interoperability and secure access to various services in different domains such as the digital economy, health systems, sustained energy and the protection of the environment, security and safety, life at home, in the cities, and in transportation systems.

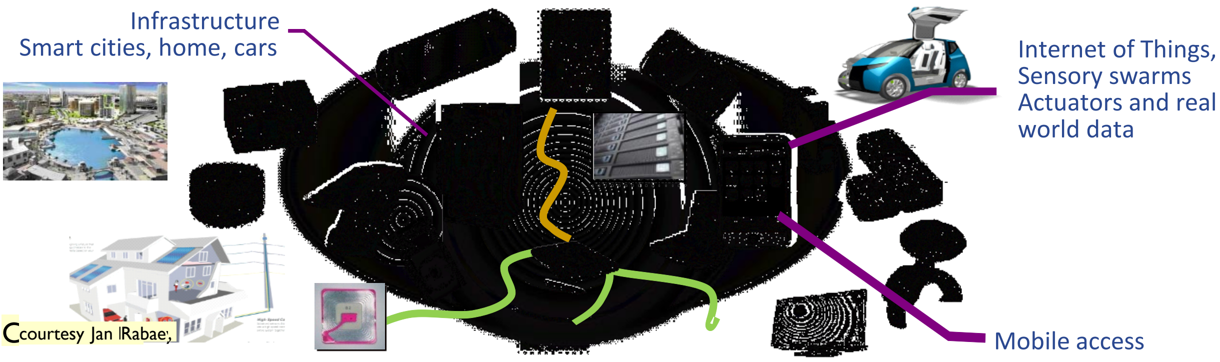
Making these benefits available depends fundamentally upon communications, the interfaces between Smart Systems and communications, and the performance enhancements that Smart Systems themselves can bring within communications systems.

Technical Challenges

The figure below shows the global integration of societal challenges in the future hyper-connected world. The challenges, which Smart Systems can contribute to solving are:

- Energy efficiency: 10 times higher battery life time of connected devices.
- Connectivity: 10 to 100 times faster end to end connectivity for both fixed and mobile access.
- Spectrum: 10 times higher spectrum efficiency.
- Less EMF exposure of the population: Decrease by 50% the exposure of the population without compromising the user's perceived quality.
- Interference mitigation in critical situations.

The communication infrastructure will include distributed computing nodes (micro servers) to ensure efficient content delivery to the users and applications.



Research priorities

The research priorities for Smart Systems for Communications need to reflect and link to advances being developed in the network and IT security industry and in academia (the related Strategic Research Agendas of NetSoC and Fire), as well as the directions suggested by societal challenges and expansions in applications. Several priorities are outlined below.

Resource management of communications must undertake new directions in the years to come:

- Conventional power optimization must turn into green energy optimization. Centralised and distributed networks and terminals (whether personal or M2M/IoT) require adaptation to energy efficient needs. This includes the energy per bit involved when processing or emitting, as well as the number of bits to emit based on improved communication protocols.
- Spectrum allocation and optimization through opportunistic spectrum policies must be developed through sensing and mutual cooperation between Smart Systems, between Smart Systems and the network, and also enabled by Smart Systems.
- Strong research on interference management is needed in order to provide intelligent spectrum allocation at the Smart System level. Hardware is to be considered in the loop for new waveforms and protocols. Interference mitigation in critical situations, such as hospitals, airplanes etc must be developed. Individuals are demanding reduced exposure to Electro-Magnetic Fields.
- Smart Systems need to be devised and exploited to bring high information integrity, network and service reliability and availability, and resilience to potential cyber-security threats. Trust and privacy protection in networks will require new communication strategies at network or physical layer level, such as those based on mutual information limits, distributed data flow within the network nodes or data storage spread over several smart systems to increase data concealment.

A large increase of Short Range Radios is foreseen:

- Minimal power consumption is demanded to enhance the life time of battery operated and harvested devices but today radio communication still represents some 50%-85% of the total power consumption of miniaturised systems.
- Interoperability is demanded at all levels, with multi-standard short range, worldwide availability and connection to the backbone. Also technology needs to be developed for a accurate, efficient in-door localization to complement outdoor GPS
- As short range radios module will be integrated into different Smart Systems and systems-on-chip, the radios need to be transferable over different technology nodes, requiring more efficient RF architectures.

Linking several sectors and subsectors to support sensor networks and wireless Internet of Things:

- Interoperability between, for example, M2M, smart home, and body (linking personal and building data for improved context) will be necessary.
- Body signals need to be defined for body networks as well as implants and gaming, while avoiding interference.

Various and numerous contributing technologies are needed, for example:

- New antenna materials and RF amplifier architectures are candidate solutions for wide band radios while optimizing energy and RF spectrum efficiency.
- New systems-in-package to co-integrate new antennas, fast RF circuits, smart sensors, nano-electronics, and embedded protection mechanisms while preserving form factors, reliability and security.
- Another trend is the direct embedding of Smart Systems into new materials and objects. There are several reliability and risk factors to resolve, along with tighter mechanical constraints, thermal insulation and reduced heat removal, and more direct exposure to chemical, mechanical, electrical EMC, and thermal impacts.

Introduction of Smart Systems

Communication networks will be used in the future to connect objects more frequently than connecting people, and embedded systems in automobiles, traffic lights, security systems, home appliances, industrial equipment and retail displays will be able to learn, adapt and react to the needs of our everyday lives.

This process of change will be enabled by several and different generations of Smart Systems, some of which are already in everyday use:

- MEMs based sensors are present in smart phones and tablets to trigger the screen position and attitude.
- As a second generation, sensors are used together with interactive map information to provide predictive navigation to the user.
- As a third generation, the sensors are used to adapt the RF power in some recent phones, taking into account the phone position in respect of the human body, permitting lower individual electromagnetic field exposure.

Nano-electronics together with embedded firmware, software packages and Smart Systems will result in heterogeneous integration, pushing the limits of integration towards System-in-Package functionality.

Applications such as this will demand more performance and connectivity while consuming less power and shrinking into smaller and smaller form factors on substrates made from new materials, or embedded directly into products.

European position

Europe has been the world leader in telecommunication standards and solutions and its manufacturing, but has lost this general momentum in the last decade.

Today Europe's more specialist strengths and world leaderships are with secure solutions (SIM card, TPM components, network security), RF designs, smart sensors and smart power devices.

Europe is the leader in applications requiring reliability, safety and security, and related applications are demanding solutions with more connectivity.

In summary; the telecommunication and Internet infrastructures are gradually becoming critical for Europe: paving the way for a fully connected digital economy, modernising other industries, and enabling future smart cities, smart services, and smart industries

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Smart Systems for Communications: EU Strengths & Research priorities

Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Sector as a whole	•Big established market	•Supply chain has vital elements outside Europe	•High margins are in service provision, which will be augmented through interconnecting Smart Systems	•Low margins could preclude EU manufacture •Culture of privacy •Lose manufacturing skills as volume leaves the EU
Optical networks	•Major players in EU, Alcatel-Lucent (ALU) •Installed infrastructure •High demand		•Airframes, automotive •Near Field Optical Communication •Preserving bandwidth through Smart Systems	
Wireless networks	•Good semiconductor supply chain •Strong providers of secure solutions •Strong IP portfolio •EU analogue skills are world leading, but scarce	•Regulatory process slow •Manufacturing capability for ever-reducing line widths has hit the investment end-stop	•Increasing use of untethered devices •Smart re-use of frequencies and beam steering, •e-services, billing and payments	•Analogue skill base , necessary for Smart Systems implementation, is shrinking
Personal & Mobile	•Wide installed base, infrastructure and market •Enthusiastic customers •Speciality B2B businesses •Global players for sensors and know-how	•Smart phone and tablet manufacturing weak in Europe	•Management and safe-keeping of personal data •Speciality B2B opportunities •Customisation of mobile device form and function	•Major security failure could set the whole sector back
RFID & Internet of Things	•EU an early investor in IoT knowledge •Dozens of Smart City projects in the EU	•Shortage of skills and entrepreneurial capital	•Streamline logistics throughout the economy •Transverse through all application sectors	•Protection of confidentiality •Cyber attack •Domino effect of interdependence

Sub-sector	Priority actions	Longer term actions
Sector as a whole	•Research how Smart Systems might reduce EU vulnerability with regard to RF and security technologies	•Manage the migration of smart technology into sectors outside communications (Transport, medical etc)
Optical	•Research into the mix and optimum partition of electronics and optics •Miniaturisation to implement flexibility and agility in optical systems (Optical-system-on-a-Chip)	
Wireless	•Spectrum management through smart technologies, as smart systems proliferate •Multimodal portable systems •Privacy challenges •Multi-physics design and simulation •Evolution of wireless protocols and of network architectures in line with new capabilities brought by smart systems •Green Energy Management through mobile/networked Smart Systems •Smart management of network overloading (device to device communication, self organizing networks, resilient networks)	•Smart antennae, adaptive materials and multifunctional materials with radio properties •Ensure interoperability between smart systems belonging to different networks •Encourage education in the analogue domain
Personal & Mobile	•Develop use of universal smart devices with protected personal data, multiple protocol and multi applications •Understand and evolve business models recognising "always connected" •Actions to predict and intercept with the products, needs and standards of the future (such smart clothes, mobile vehicular architectures)	•Preserve strengths in security and standards •Defend the know-how in interconnection of technologies and devices •Cognitive terminals optimising use of resources, channels and modes •Understand convergence with Internet of Things
RFID & Internet of Things	•Develop robust IoT systems and procedures •Develop new use and insert intelligence within IoT sensors •Develop IoT business models and opportunities •Develop cyber defences appropriate for IoT	•Ethical, acceptability and security issues

Quick links:

Sector overview | Optical | Wireless | Personal & Mobile | RFID & Internet of Things

Optical communications

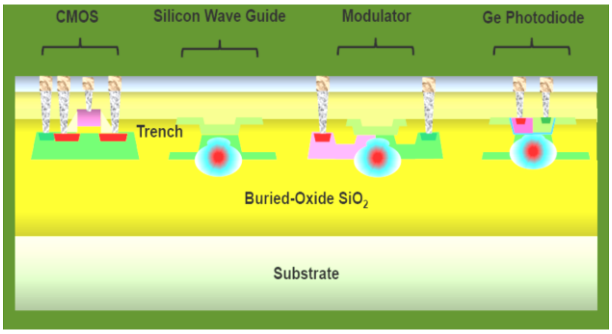
Overview

This subsector description addresses firstly the role for Smart Systems in optical fibre communications, and secondly the merging of photonics and silicon technologies.

Photonics itself is covered by the Strategic Research Agenda of Photonics21, in respect of many of its applications and the underlying enabling technologies.

Opportunities for Smart Systems

- Bandwidth is pushing optic fibre technology. Smarter devices promise to use less backbone resource. Intelligence is also demanded in the fibre in the last mile, as well fibre in the home terminals to be smart, so allowing an “all-light box” and billing advantages.
- Silicon photonics is shaping up as the prime candidate to address chip and electronic module I/O limitations to provide system-wide high-bandwidth density with extreme energy efficiency. Real-time sensor fusion and virtual sensor creation
- Smart systems may assist with energy distribution within networks, and optimising its use.



M. Zuffada, STMicroelectronics, Nanoforum Munich 2012

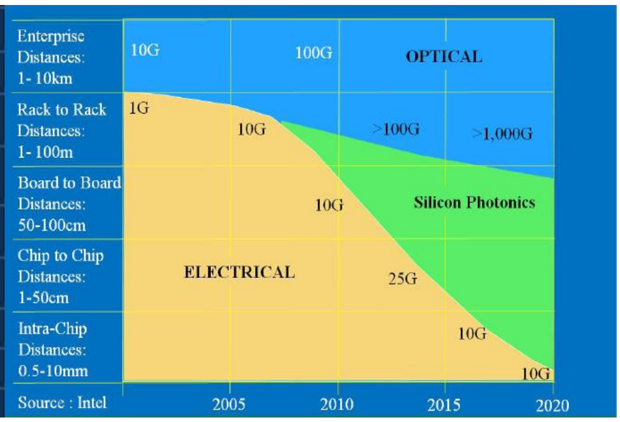
Hurdles to be overcome

- Material selection for close integration of photonics with electronics.
- Systems in package to co-integrate extremely fast III-V circuits with silicon-based circuits for fibre transmission, for new computing or RF system on chip or processing of electromagnetic signals.
- Very high throughput components.
- Extend towards low THz transmission for indoor communications.

Applications

- The internet is based on the proviso that the network is dumb and that the intelligence is at the terminals. Smart Systems could bring autonomy to the services that keep the network working, self diagnosis, self healing, self managing and adapting to new usage
- Petabit Core Networks with intelligence starting centrally, but becoming more distributed
- Smart optical fibres in airframes and cars
- RF and Photonics together with nano-electronics and packaging will bring new Smart Systems, such atomic clocks, RF processing and multi-spectral analysis.

Year		2012	2015	2018	2021
Application		Active Cable	Opto_Backplane	Opto_Board	Opto_Chip
Technology		200 mm 130 nm	300 mm 65 nm	300 mm 32 nm	W2W Bonding
Tech. Breakthrough		Ref	SDM PAM-8	Micro_Ring WDM	Integrated Lasers MFC
Data Rate per link		10 Gbps	30 Gbps	200 Gbps	800 Gbps
Parallel Link (4x)	Aggregate Bandwidth	40 Gbps	120 Gbps	800 Gbps	3200 Gbps
	Energy/bit	20 pJ/bit	7 pJ/bit	2 pJ/bit	0.7 pJ/bit
	Size	10,000 mm^3	2,500 mm^3	1,000 mm^3	100 mm^3
	Module cost	4 $/Gbps	1 $/Gbps	0.25 $/Gbps	< 0.04 $/Gbps



Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

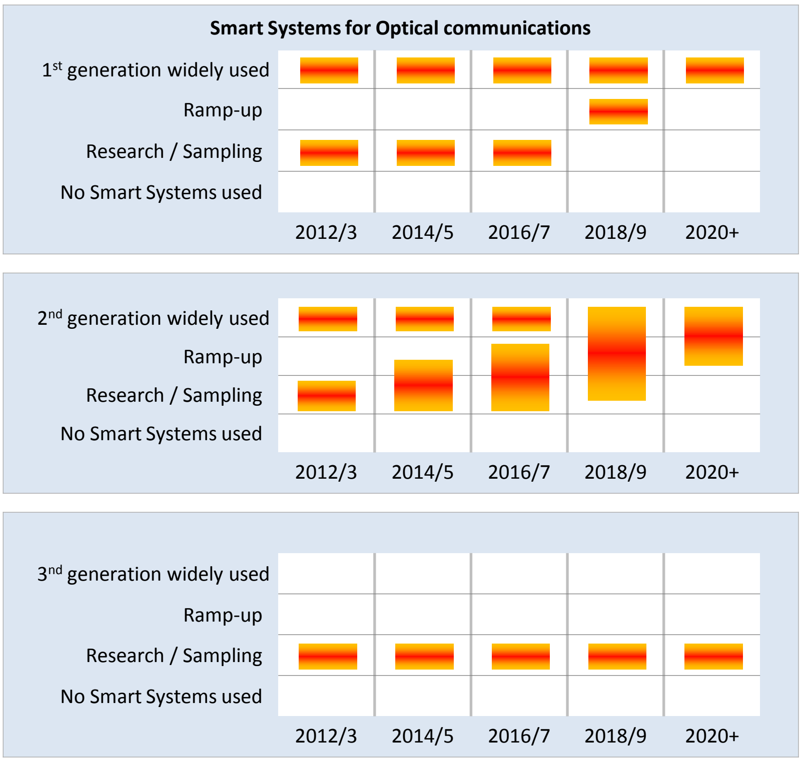
Mixed photonics-silicon sensors are applied in environmental sensors, with distributed intelligence.

2nd generation Smart Systems are predictive and self-learning.

In network infrastructure, intelligence has started centrally, but needs to be developed to become more distributed, and adaptable to differing network demands.

3rd generation Smart Systems simulate human perception/cognition.

The high data rate of photonics makes this 3rd generation very challenging. However new smart “cognitive” approaches to optical computing are at the stage of early development.

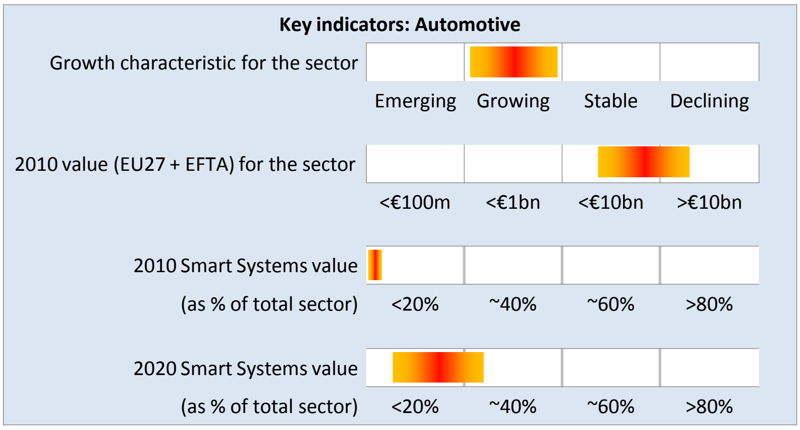


Sector forecast

Europe has a good position in photonics today, in lighting, in the communications backbone, industrial laser technologies and bio-photonics, with a value of €60bn in 2012 increasing at 8% per year.

The high-volume, low cost production techniques of CMOS Silicon Photonics has the potential to create a new technology enabler for a wide range of applications from broadband communication to consumer, to sensors for environment protection, thus also enabling green and efficient energy, and medical bio-sensor markets.

(Source M.Zuffada, Nanoforum, Munich November 2012)



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Quick links:

Sector overview | Optical | Wireless | Personal & Mobile | RFID & Internet of Things | EU Strengths & Research priorities

Wireless communications

Overview

The interconnection of personal and mobile communications, the Internet of Things, the interconnection of short range wireless into cellular communications, near-field transactions and international long-haul communications by satellite and short-wave systems illustrate the shear breadth of ubiquitous un-tethered connectivity for an ever wider range of applications.

Opportunities for Smart Systems

Smart systems are critical for unlocking further potential, by improving access to key resources:

- Ultra low power wireless communications for energy scavenging devices.
- For lower microwave frequencies, smart frequency-agile transceiver solutions improve the efficient use of the available spectrum.
- For the higher millimetre-wave frequencies, smart RF front-ends can enable more directive solutions, enabling high-throughput connections to the core.
- Improved intelligence in untethered devices enables cognitive radio, promising flexible/dynamic spectrum use, increased energy autonomy, better capacity, lower cost, lower environmental footprint, and increased reliability and availability.

Hurdles to be overcome

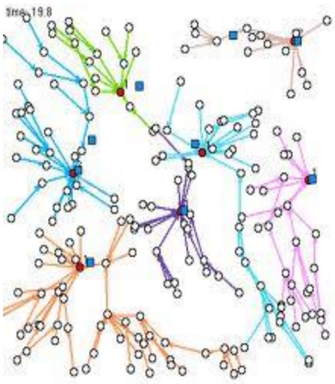
Wireless communications are largely defined by four key, limited resources:

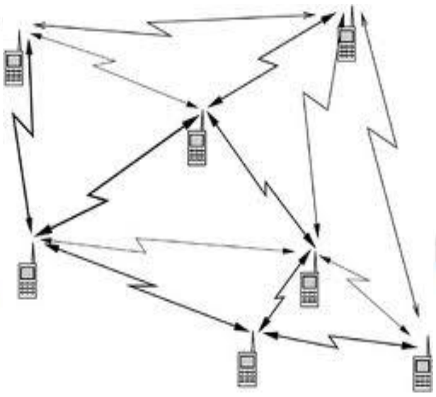
- Spectrum, and increasing demands upon it.
- Connectivity to the core, wired/fibred networks.
- Energy availability in smart sensors and in mobile devices.
- Ultra low-power protocols, especially for items connected to the Internet of Things

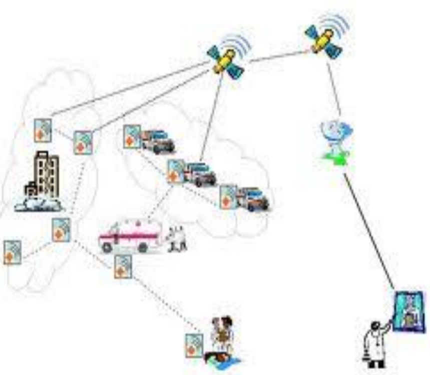
New applications need also to cope with Heterogeneous network routing and Security mechanisms

Applications

- For the delivery of global, high-bandwidth personal communications: An invisible, ubiquitous small-cell network of miniature access nodes seamlessly collaborating and self-optimizing, with agile, multiband transceivers exploiting licensed, unlicensed and dynamic access spectrum.
- For emergency-response networks: Dynamic, high-bandwidth networks quickly formed by a smart mobile, ad-hoc networks of highly intelligent, self-configuring nodes.
- For low-cost, wireless backhaul of base stations, access points and wireless gateways: Millimetre-wave transponders with smart, electronically steerable RF front-ends minimising installation and maintenance costs.
- For body area networks for the management of chronic illnesses: highly-energy-aware smart devices with smart energy scavenging to maintain the communications required, while maximizing battery life.







Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

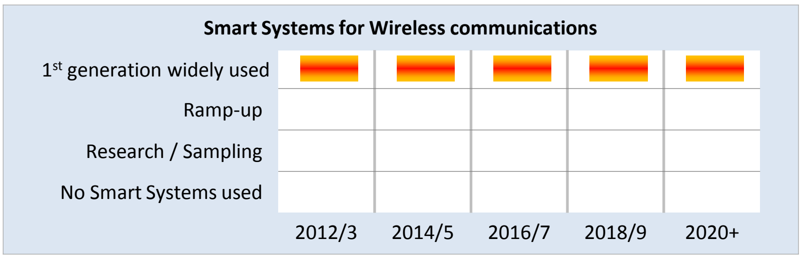
One-way paging and control systems such as analogue pagers and digital car-key fobs; device to device direct communication on a free spectrum.

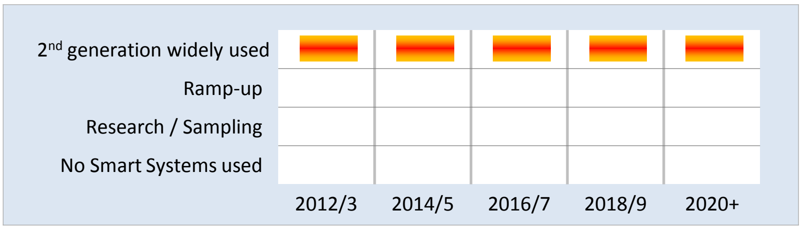
2nd generation Smart Systems are predictive and self-learning.

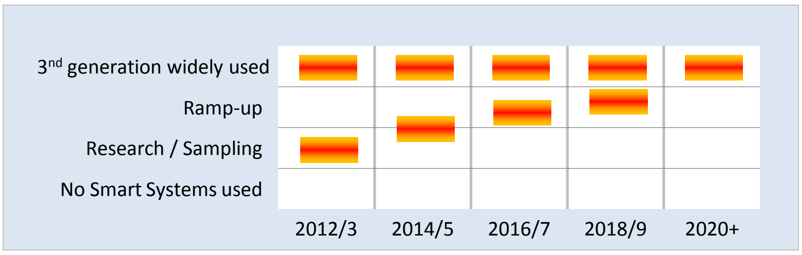
Adaptive modulation for 3G smart phones; transmit power control for home femtocells; frequency-agility in RF transceivers.

3rd generation Smart Systems simulate human perception/cognition.

Dynamic self-optimizing network technology for dense small-cell deployments; ad-hoc networks for emergency response communications.







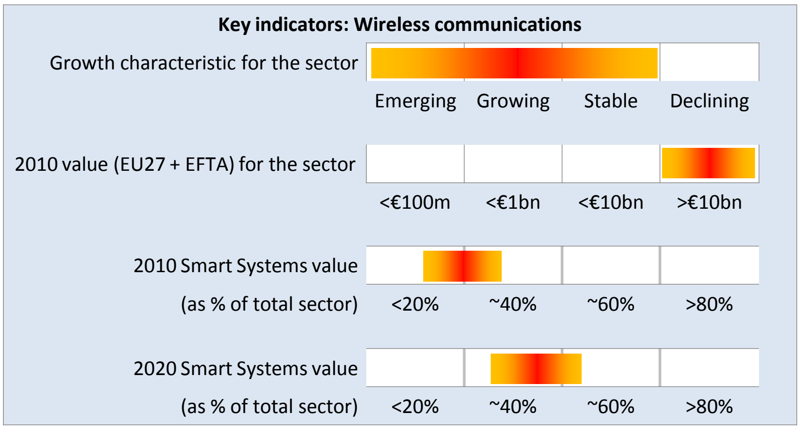
Sector forecast

The wireless communications sector is being driven by two major trends: the explosion in mobile broadband communications (the urban density of smart phones to rocket from 400/km² in 2010 to 12,800/km² in 2015 [1]) and a dramatic increase in M2M connections (ten-fold increase between 2012 and 2020 [2]).

Because of the spectrum and energy resource bottlenecks that need to be relieved, the fraction of that total addressable market captured by Smart System technologies will, by necessity, increase dramatically.

[1] "Metro Cells Business Case: A cost-effective option for meeting growing capacity demands", Alcatel-Lucent, 2011

[2] "Global M2M Connections Market Forecast & Analysis", Strategy Analytics, 2012



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Quick links:

Sector overview | Optical | Wireless | Personal & Mobile | RFID & Internet of Things | EU Strengths & Research priorities

Personal & Mobile communications

Overview

Personal and Mobile communications currently rely upon smart phones but may extend in the future with more personal data in mobility and new support measures such as body area networks and ambient assisted living.

With smart phones, many applications are already available such as speech, camera, GPS navigation, multimedia, mobile messaging and e-mail, and internet web access.

Opportunities for Smart Systems

- Different form factors with a high degree of security. Universal smart but protected devices with the convergence of mobile devices for multi-applications.
- Body area networks with medical sensor readouts; the mobile phone becomes a hub, and entry point for services, multimedia, digital rights.
- Similar enabling technologies going to the Internet of Things and the Machine-to-Machine sectors.
- More mobile and personal services, including for example the transmission of touch and smell.

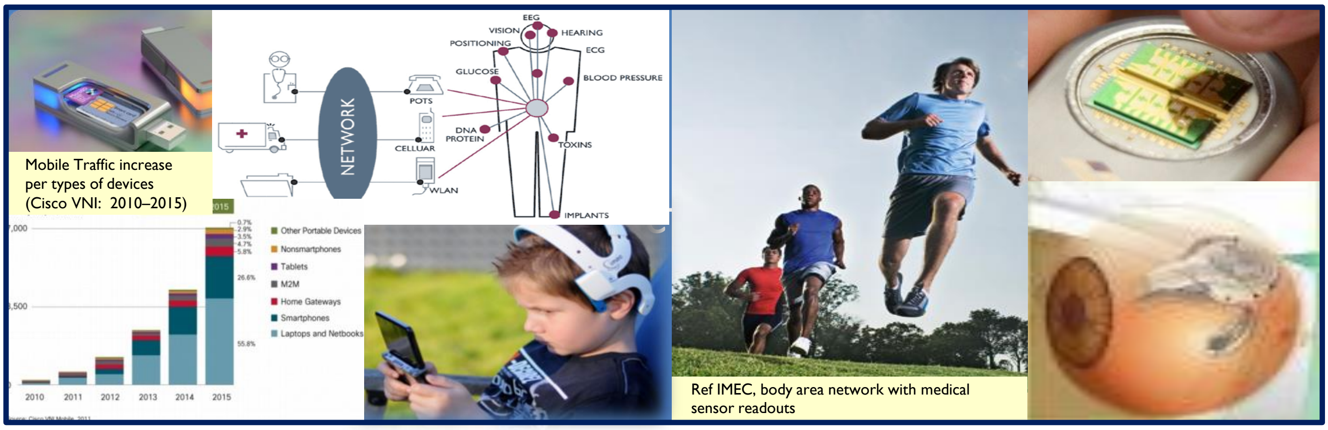
Thales

Hurdles to be overcome

- Protection of personal data with multi-form, multiple protocol and multi applications mobile devices. Address when necessary the related individual questions of privacy concerning mobile tracking.
- Trusted Mobile devices and services.
- Embedding of Smart Systems into functional materials, requiring more miniaturisation, new packaging and new RF architectures
- Reduction of Electro-Magnetic Field exposure.

Applications

- Many applications together will make use of smart phones and tablets, and in future we imagine on new structures, such flexible ones, consolidated card, head-up augmented reality glasses or helmets.
- Internet glasses and contact lenses: huge growth predicted, but privacy issues may apply
- Connected gaming using body signals: EEG, eye movement, may change ways of communicating.
- Based on an urban life, migration to mobile device payment (mobile phone tablet): remote payment; e-health care, e-prescription, e-monitoring, e-health record, automated services for endangered persons, all with a strong need of privacy and protection.
- Secure portable office, including browser, ID and keys on a portable device permitting connection from everywhere.



Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

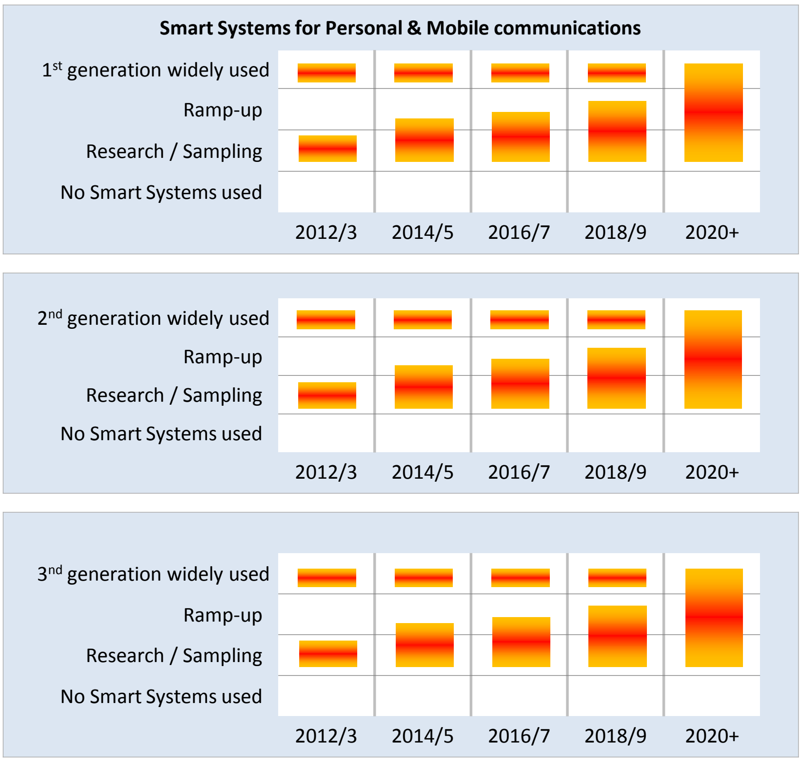
MEMS-based sensors such as microphones, accelerometers and gyroscopes are already present in smart phones and tablets.

2nd generation Smart Systems are predictive and self-learning.

Smart clothes with sensors/actuators could share their information with the user or remote users and can perform automatic actions according to interpreted results from their sensors.

3rd generation Smart Systems simulate human perception/cognition.

In the future clothes themselves could process the data collected from all the sensors/actuators and adapt to the environment and the comfort of the wearer.



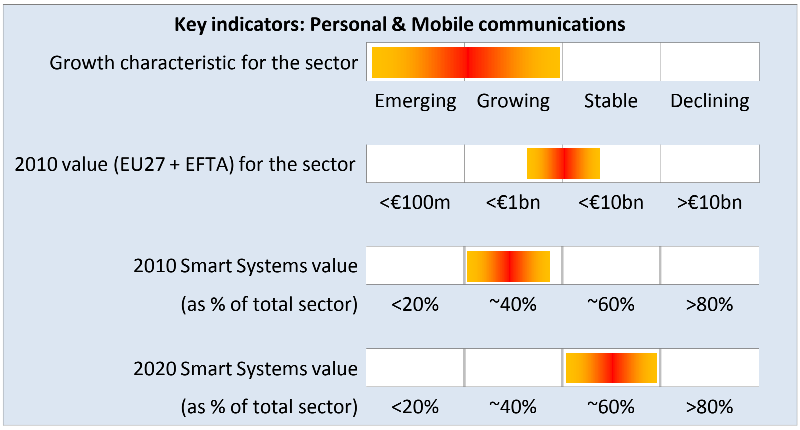
Sector forecast

Smart phones and tablets already include attitude sensors, temperature sensors, cameras, microphones and a sophisticated Human Machine Interface.

45% of users in 70 countries today use smart phones for web or social connectivity. These devices have overtaken mobile phones and tablets, and may overrun PCs. Sales of tablets are growing about 150% per year, with about 200m units shipped in 2013 according to IDC.

Through the Internet of Things this use will grow to interact with home, cities, regional, transportation on the move and international Smart Systems.

Europe has leading component makers and service providers, but is no longer leading in product integration for Personal & Mobile communications.



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Quick links:

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RFID & Internet of Things

Overview

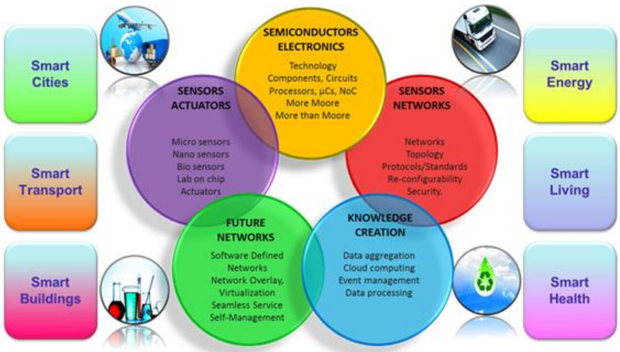
In the Internet of Things, “smart things/objects” are expected to become active participants in business, information and social processes through being enabled to interact and communicate among themselves and with the environment.

By exchanging data and information sensed about the environment, objects will react autonomously, not only between themselves but also to real /physical world events, by running processes that trigger actions and create services with or without direct human intervention [1]

Opportunities for Smart Systems

- Almost unlimited roles for wireless/cellular smart modules in automobiles, within homes, new buildings, retail outlets, smart cities, mass transport, health monitoring, smart grid, manufacturing and industrial equipment.
- New small form factor systems integrating several enabling technologies such as nano-electronics, smart sensors, antennas, low footprint RF and short range radios, cyber-physical and embedded systems, and low footprint embedded software.

[1] The Internet of Things 2012: New Horizons – ISBN 978-0-9553707-9-3, 2012



Ovidiu Vermesan, Sintef

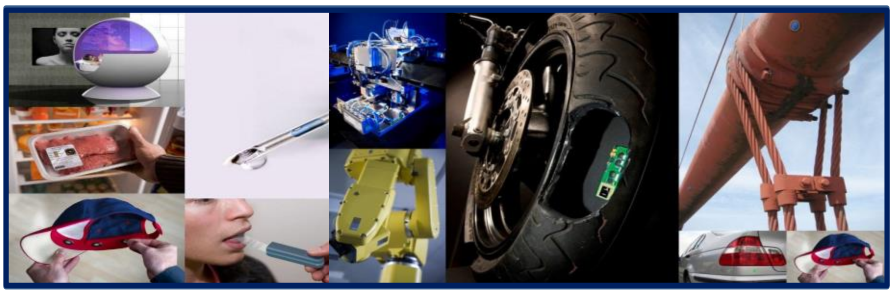
Hurdles to be overcome

- Novel energy harvesting techniques.
- Ultra low footprint and low power autonomic smart devices and systems.
- Secure, reliable, safe and Self-management, -healing and –configuration.
- Europe’s leading applications are mostly with harsh and potentially uncontrolled environments.
- Worldwide Standards and interoperability between devices coming from different vendors.

Applications

Today communication via Internet is through computers, tablets and smart phones. In the future, the Internet will be everywhere – in clothes, furniture, on walls, in the street and within manufacturing production lines.

- Wireless and smart technology will enable real-time locating systems (RTLS) to support the process of testing and verifying vehicles coming off the assembly line while tracking them as they go through quality control, containment and shipping zones.
- Smart data collection from surrounding ‘things’, such as the vehicle parts themselves, the supporting transportation infrastructure (road/rail/etc), other vehicles in the vicinity, and sensors in the loads being carried (people, goods, etc).
- Smart solutions for fare collection and toll systems, screening passengers and bags boarding commercial carriers as well as the goods moved by the international cargo system.
- Smart air freight containers (smartULD) with sensor monitoring, triggering alarms autonomously, Internet connected, ad-hoc networks of ULDs, energy harvesting, and integrated RFID-based identification of goods.



Sywert Brongersma, Imec NL

Introduction of three classes of Smart Systems

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1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

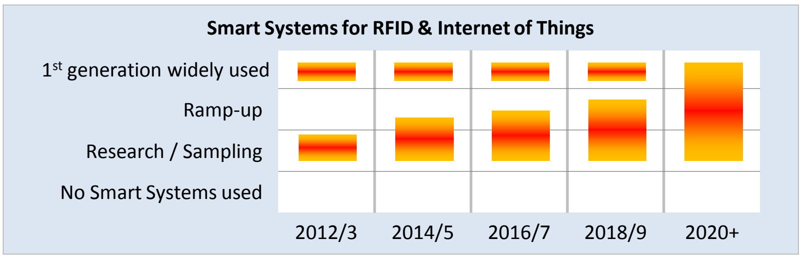
Numerous simple examples are deployed in very high volumes, including RFID tags and retail displays.

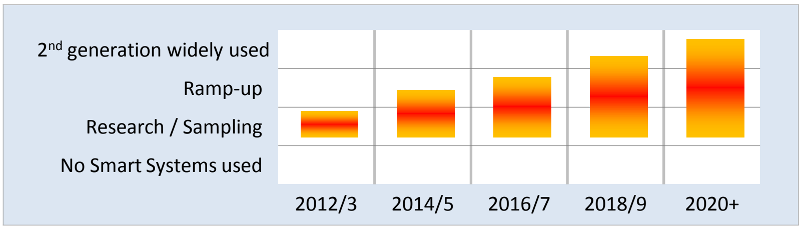
2nd generation Smart Systems are predictive and self-learning.

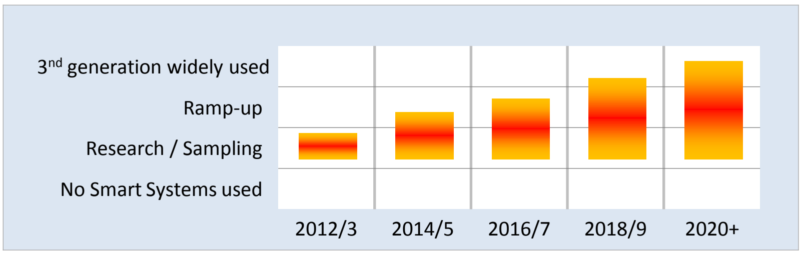
The Internet of Things will exponentially increase the scale and the complexity of existing IT and communication systems: Autonomy will become an imperative requirement for these systems

3rd generation Smart Systems simulate human perception/cognition.

Whilst wireless sensor networks and cognitive networks with self-adaptation will offer enormous advantages to the Internet of Things, unwanted behaviour must be eliminated for safe and secure operation.





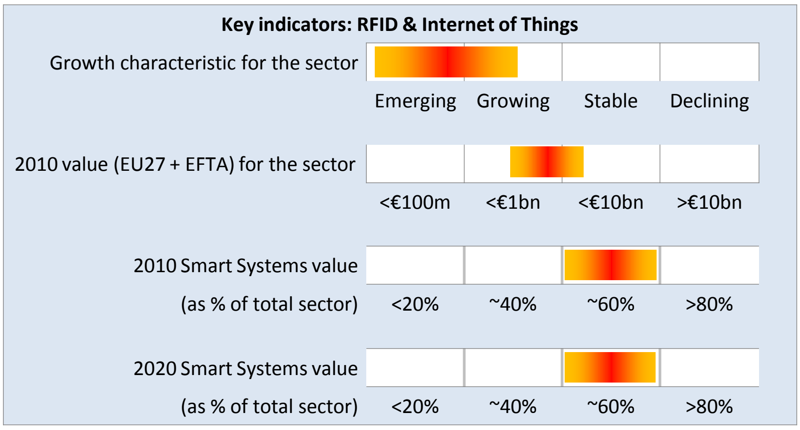


Sector forecast

In 2011, there were over 15 billion devices on the Internet, with 50 billion+ temporary connections. Many people in the developed world already have three or more full-time devices connected to the Internet, counting PCs, smart phones, tablets, televisions and the like.

By 2020, there will be over 30 billion connected things, with over 200 billion temporary connections.

Key technologies will include embedded sensors, image recognition and short range radio/Near Field Communications (NFC). Smart Systems will "collect, transmit, analyze and distribute data on a massive scale" (Sources: Gartner and Cisco)



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Quick links:

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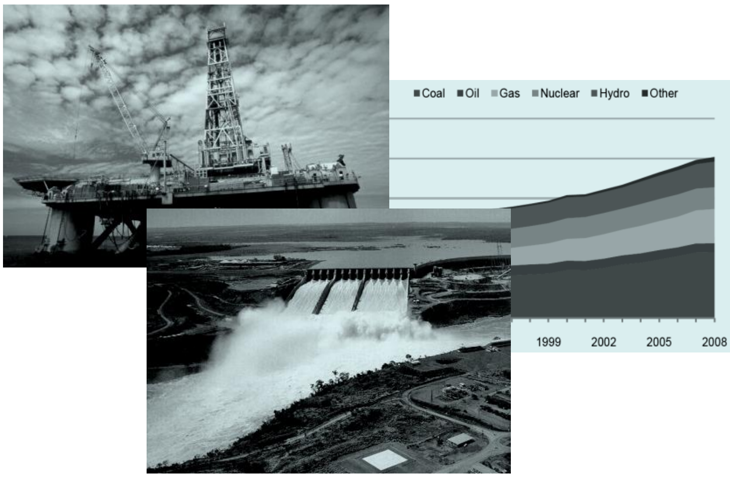
SMART SYSTEMS FOR ENERGY

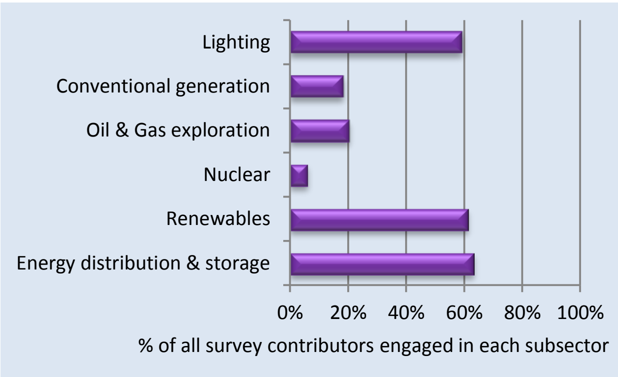


Smart Systems for Energy

Overview

Energy is behind almost every class of human endeavour. Civilisation depends upon care, security and efficiency at every stage from the discovery and unlocking of energy sources, through the storage and distribution of energy and on to its final use.

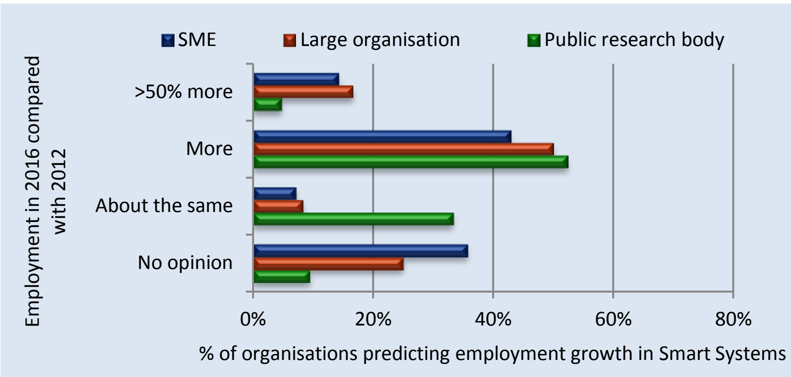
Smart Systems, with their capability for rapid response either autonomously or through networking, can safeguard and optimise every aspect of this critical chain.



Profile of subsectors

For the IRISS 2012 survey, 49 Smart Systems providers including 26 companies, representing those engaged in the energy supply chain from research through to market servers, revealed clear distinctions between subsectors (illustrated left).

Exploration and conventional/nuclear generation are not yet a focus for Smart Systems, but Lighting, Renewables and Distribution & Storage figure strongly in the activities of this supply chain.



Growth prospects: Organisations

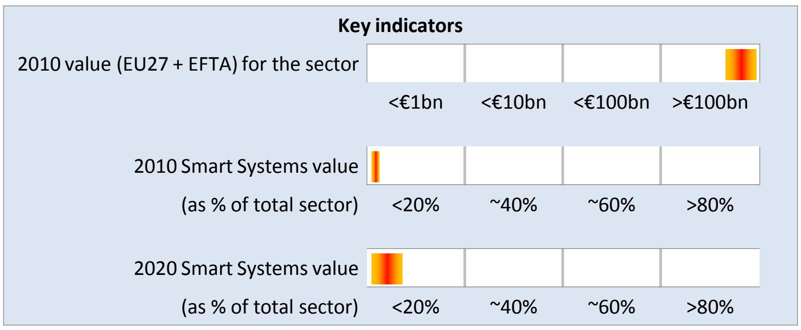
Of the Smart Systems providers surveyed, the great majority forecast employment growth, with a significant proportion of companies predicting headcount increasing by more than 50% by 2016 (illustrated left). There were no predictions of reductions in headcount.

A comparable picture emerged for organisational growth in financial terms.

Growth prospects: Whole sector

The Energy sector in EU27 + EFTA is immense in value (€1210bn) or nearly 10% of GDP. Currently Smart Systems account for possibly <1% of this, but could rise to ~2% (€24bn) by 2020, which is a very large potential that warrants further investigation.

The applications are notably in renewables and energy-saving control systems.



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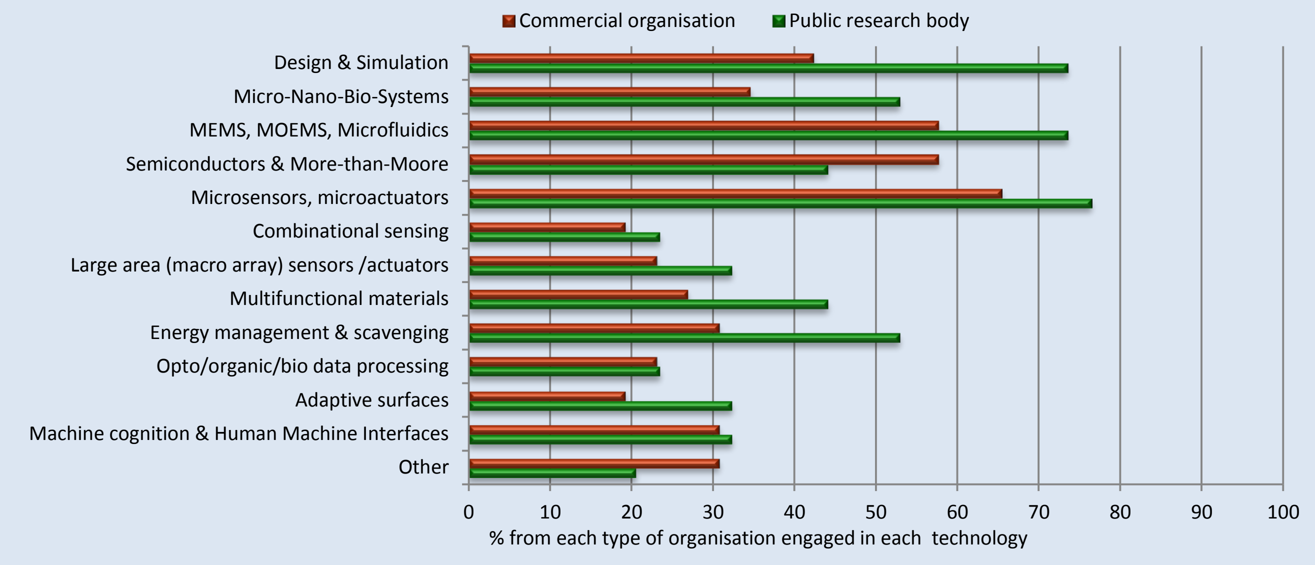
Underlying technologies



Energy companies reported three front-running technologies respectively: Microsensors & Microactuators, MEMS, MOEMS and Microfluidics, and Semiconductors & More-than-Moore technologies.

A high proportion of Public research bodies report undertakings in Energy management & Scavenging, which seems to have penetrated rather less into commercial application than might be expected, considering the potential advantages of the technology in this sector.

Taking into account the above and also the sector profile, key issues for support action should therefore include:

- Strengthening the exploitation of Energy Management & Scavenging technologies,
- Introducing Smart Systems into electricity generation
- Identifying how Smart Systems might improve the identification of new energy resources

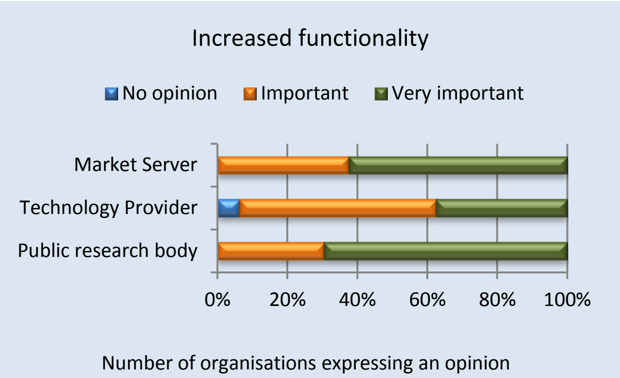
Drivers and barriers

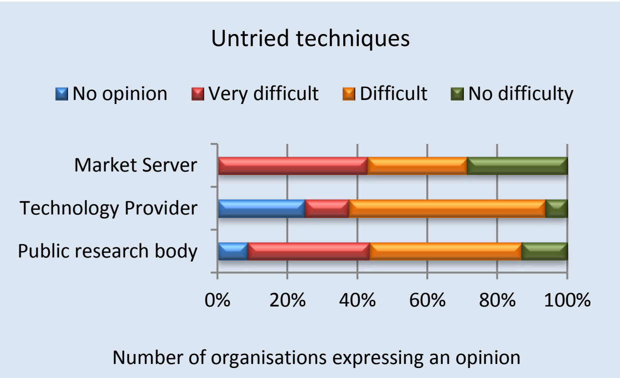
The survey of Smart Systems providers to the Energy sector rated "Increased Functionality" as the most important driver compared to, in descending order, Reduced Cost, New Markets, Global Competitiveness, Increased Reliability, Simplicity in Use, and legislative drives to compel the use of new devices or techniques.

The most obstructive difficulty reported was "Untried Techniques". This is instructive as the Increased Functionality Driver is most likely to be satisfied by Untried Techniques.

Accordingly, action should therefore be considered to mitigate the risks entailed in the uptake of Smart Systems for example by:

- Encouraging tighter inter-disciplinary R&D
- Supporting the development of holistic simulation tools with coverage from concept, through manufacture to in-life service





The sector in more detail

The Energy sector is driven primarily by resource supply and demand, but also by geo-political factors. Compared with other industries, major shifts in power generation, choice of resources, technologies or changes in consumption are typically spread over very long cycles, often decades to full implementation.

Estimates of total reserves of major energy resources are often subject to debate, especially for fossil fuels, but nearly all sources agree that the reserves available are a function of the price that one is willing to pay for extraction. In a related fashion, an increase in the cost of resources opens the door to innovation in energy conservation and better energy efficiency, thus effectively increasing the limits of reserves.

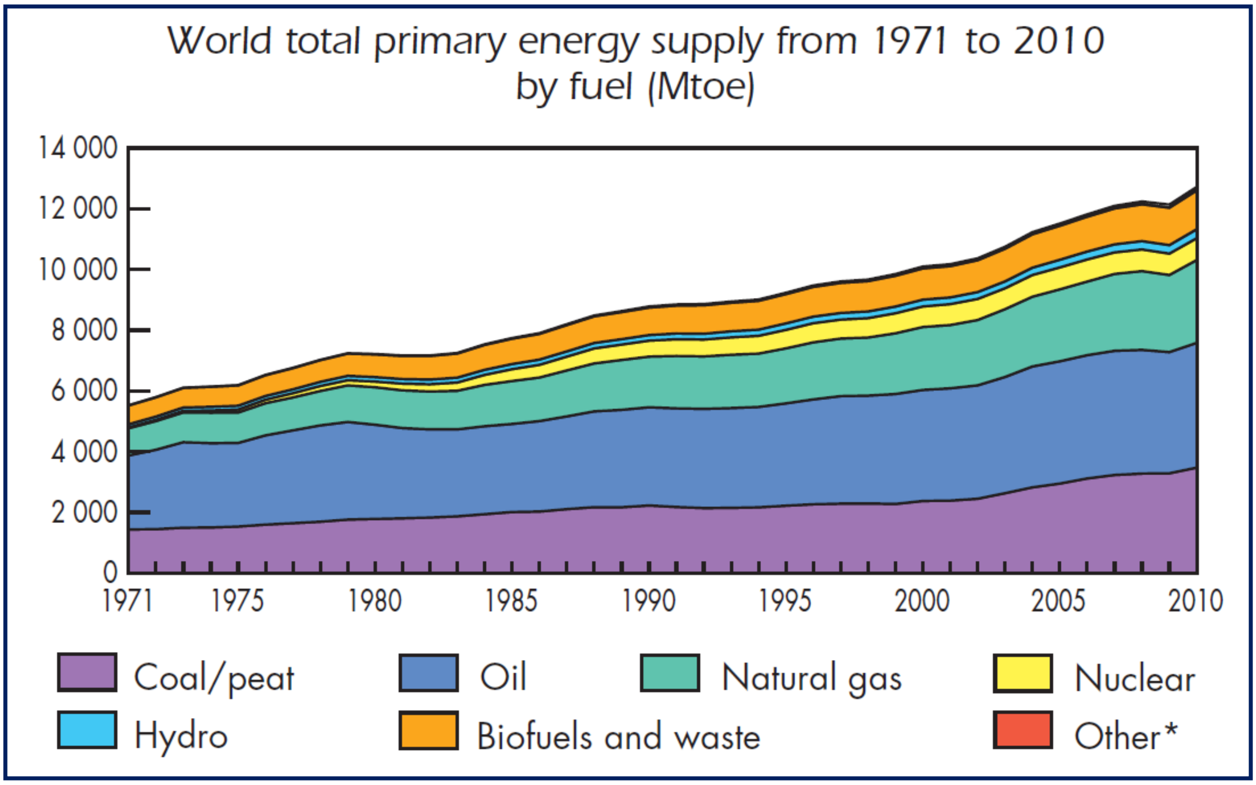
The main drivers for the energy sector are :

- Availability of resources (supply side economics).
- Governmental policy (regulations, taxation, incentives).
- Geo-political factors (dependency on imports, risk/occurrence of abrupt disruptions of supply).

Smart Systems will play an important role in the ability for Europe to gain energy independence by mitigating the risk of energy supply disruptions.

The energy subsectors in brief

- Lighting – is being completely revamped with the introduction of solid-state / intelligent lighting.
- Fossil Fuelled Generation – fossil fuels continue to grow in the energy mix, focus is on efficiency .
- Oil & Gas Exploration – requirements for new technology for deep sea, oil sands and shale gas extraction.
- Nuclear Energy – flat growth in past ten years, but global capacity will increase through 2050. Technology needed also for decommissioning.
- Renewables – despite major advances in technology, deployment is lagging
- Energy Distribution, Storage and Use – major focus on increasing overall efficiency, reducing transmission and conversion losses. Storage remains problematic.



**Other includes geothermal, solar, wind, heat, etc.*

Benefits of Smart Systems

Smart Systems provide the fundamental tools to directly address the two most important vectors for secure, cost-effective energy – improving efficiency and maintaining supply. Some examples include:

Improving efficiency :

- Providing highly accurate sun tracking for concentrated solar photovoltaics (CSP).
- Regulating fuel mass flow and combustion conditions in supercritical generation plants.
- Accurately mapping the strata of the subsea floor to successfully drill into reserves.

Preventing loss or failures :

- Detecting approaching wind turbulence to avoid damage to wind turbine shaft and gearbox.
- Sensing excessive current and over-temperature in high tension power lines.
- Regulating drilling speed in oil and gas drilling as a function of drill head temperature and pressure.
- Monitoring nuclear reactor core temperature and vital flows and pressures.

Technical Challenges

- Increase operating temperature and pressure limits of Smart systems.
- Improve sensitivity, reduce interference, enhance power management, achieve autonomy.
- Integrate signal processing at the chip level to provide basic functions without the need for system processing.
- Provide advanced algorithms for data extraction and conditioning in multi-parameter systems.

Introduction of Smart Systems

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Fuel quality sensor (2008) capable of determining the ethanol content in gasoline.

- Continental

2nd generation Smart Systems are predictive and self-learning.

Fuel quality sensor (2012) capable of sensing the chemical composition of fuel, as well as water, sulphur and gasoline content in diesel fuel.

- Continental

3rd generation Smart Systems simulate human perception/ cognition.

Next generation fuel quality system capable of analyzing the chemical composition of any fuel mixture (diesel, biodiesel, vegetable oil, organic extracts, etc.) and adapt the engine management to optimize combustion while maintaining pollution standards.

European position

Europe is leading the Smart Systems global competition in many important market sectors related to energy.

Many of the pioneering activities of the petroleum era have resulted in the development of a strong value chain in oil and gas, including producers such as Shell, BP, Total and Statoil, service providers for exploration and exploitation such as Schlumberger and Technip, and technology providers such as Sercel, Colibrys and Tronics.

Maintaining leading edge technology in Smart Systems will provide added value to the whole value chain and enhance competitiveness.

Similarly, in the power generation sector, leading examples of Smart Systems include the technology employed in the recent coal fired plant placed in service in Germany by RWE with a record 43% efficiency. Europe is also leading in Carbon Capture and Storage, with examples like Vattenfall's Swarze Pumpe facility.

Renewables, lighting, nuclear and distribution are areas in which Europe currently has state-of-the-art technology, but cost pressures are limiting the expansion of European players on a worldwide basis. A combination of creative smart systems coupled with focused legislation could improve this situation.


Advanced lighting, Neurospin (credit: Vasconi Associés Architectes)

Research overview

- Energy management Smart Systems that operate at the appliance level (smart devices), at the building level (smart home or office), at the local/regional level (smart city) and at the grid level (smart grid).
- High temperature sensors and systems for extending smart systems into new application. space in exploration, exploitation, generation, distribution and use.
- Power management systems with high efficiency and high reliability.
- Smart Systems for extremely low maintenance, autonomous renewable energy systems.

Reference

Smart Grids: from innovation to deployment, EC, April 2011; BP World Energy Outlook, 2013; WEO2012, OECD IEA


Smart Systems for Energy: EU Strengths & Research priorities

Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Sector as a whole	• Smart energy control accepted as a public and governmental principle	• Safety regulations may preclude the early use of Smart systems	• Regulation can be a major driver	
Lighting	• Good innovation capabilities in new lighting approaches and design	• LED, OLED component supply not projected to be from the EU	• Introduce Smart Systems during technology replacement cycles	• Restricted window of opportunity for replacement of incandescent lighting
Fossil fuelled generation	• Large installed base which may be upgraded and extended in life by Smart technologies		• Use Smart Systems to enhance environmental performance and efficiency	
Oil & Gas exploration	• Global centre is in the EU, with much experience that could be captured and deployed by Smart Systems.		• Autonomous robot sub-sea and airborne explorers	
Nuclear	• Safety conscious public and political environment		• Multi-parameter installation monitoring and prognosis • Robotic decommissioning	
Renewables	• Industry scale appropriate to allow innovative SME engagement with Smart Systems ideas	• Renewables often driven only by legislation	• Smart integration of microgeneration and energy storage	
Distribution, Storage & Use	• Strong network providers, supported by an excellent research base in electronics and electrochemistry a good basis for Smart Systems development	• Lost manufacturing base for secondary batteries: Cells typically come from China	• Smart systems in network safety and security, health management and prognostics • Smart domestic heat storage systems	• Public mistrust of Smart monitoring

Sub-sector	Priority actions	Longer term actions
Sector as a whole	• Encourage coordination between the Smart Grid and Smart Systems Integration communities	
Lighting	• Develop alternative principles for illumination including their control systems	• Use smart lighting infrastructure to diagnose/monitor local grid, and wider network
Fossil fuelled generation	• Combinational sensing for optimised combustion • Smart control and management of local (co) generation and microgeneration • Sensors and systems able to work in the combustion environment	
Oil & Gas exploration	• Sensors and systems for long term harsh unattended operation • Generate new procedures to ensure that Smart Systems are "Oil/gas Grade"	• Autonomous robot sub-sea and airborne explorers
Nuclear	• Radiation hard, high temperature smart sensors and systems • Smart Human Machine Interfaces sensitive to current system behaviour, and to predict future behaviours	• Non-linear forecasting of domino effects (integrate neuromorphic computation into smart systems)
Renewables	• Integrated on-roof and up-mast Smart control systems, network capable • Reduce local impact (noise, smell) from local generation – active geometry, antiphasing, higher efficiency	• Plug & play systems, including maintenance
Distribution, Storage & Use	• Smart storage electrochemistry, with EU manufacturing uptake • Intelligence at buildings level, • Agile partitioning/interaction of controls at different levels of the user/distributor/generator hierarchy • Smart HMI for users	• Smart management of combination of supply, storage devices and systems, compensating also for battery, device , equipment and network ageing

Quick links:

Sector overview | Lighting | Fossil fuelled generation | Oil & Gas exploration | Nuclear Energy | Renewables | Distribution, Storage & Use

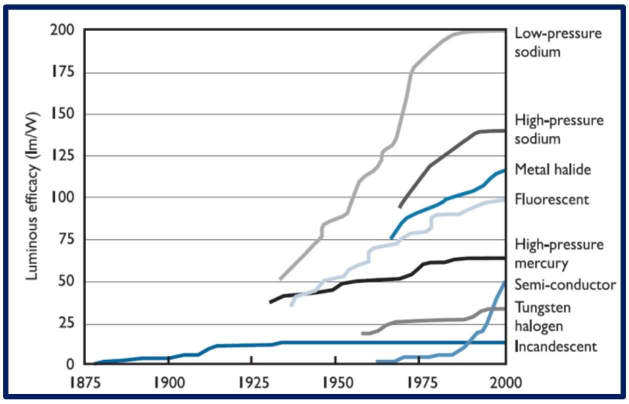
Lighting

Overview

Lighting, portable, domestic, public, industrial, safety, security, advisory and also as installed in almost every form of transport, is a major consumer of energy. Although solid-state lighting appliances are still quite expensive, lighting "on demand" is already being deployed to ease consumption.

Opportunities for Smart Systems

- Solid-state lighting is approaching the theoretical maximum efficiency – so usage, directivity, and required performance are opportunities for smart systems.
- Potential for lighting adaptation as appropriate for tasks or ambience requirements.
- Communications could be integrated into semiconductor lighting.
- Wafer-level technologies are common between LEDs and smart systems, opening the door to potential 3D "smart" integration.



Source: Lamptech, 2005 (reproduced with permission).

Hurdles to be overcome

- A large majority of lighting devices and fixtures are made in Asia, will smart systems require intimate integration within the lighting device?
- Should we still use 220v distribution for lighting, or is a lower voltage for local distribution more efficient in the long run?
- New lamps currently need to retrofit to legacy systems (sockets and fixtures).

Applications

- Basic lighting in the EU market is considered as saturated, with low margins. Smart Systems could enable a change to a "service" provision.
- Some niches – advertising, large area lighting, walkways etc are growing. There is the potential for specialised or personalised interaction with individuals.
- Smart systems for lighting might network and gain information from other application areas, for instance traffic monitoring and prediction.
- Adaptive lighting will provide efficient use of resources, enhanced user experience and improved overall safety and security.

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

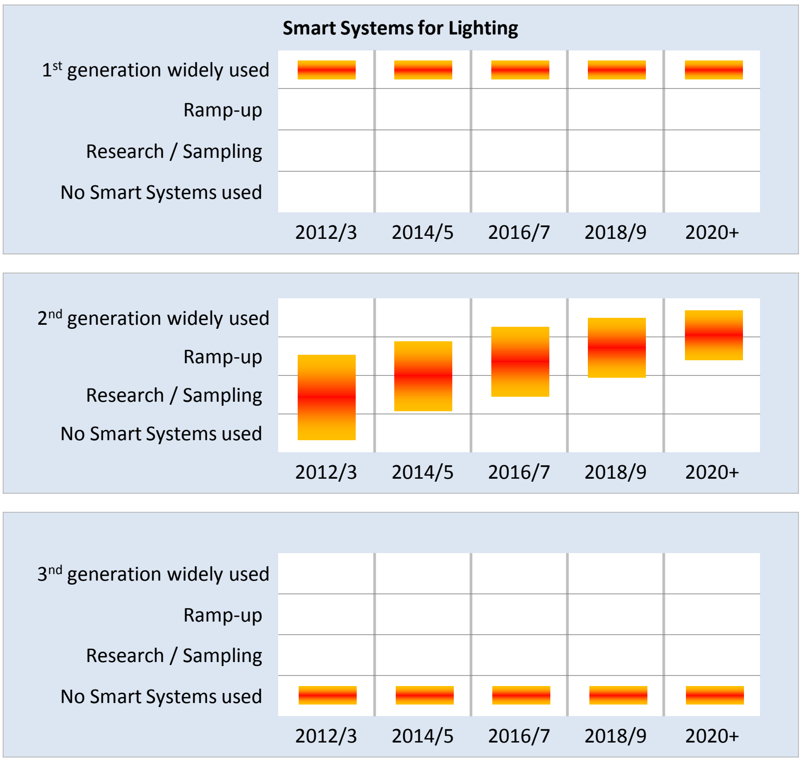
Automatic lighting, for instance motion sensors to activate lighting when occupants are detected.

2nd generation Smart Systems are predictive and self-learning.

Interlinked lighting devices, for example: lighting for a pedestrian walkway in which devices are interdependent and are activated according to usage patterns.

3rd generation Smart Systems simulate human perception/cognition.

Context aware lighting, for example emergency escape lighting which directs hotel guests away from fire detected areas, routes are "intuitively" illuminated



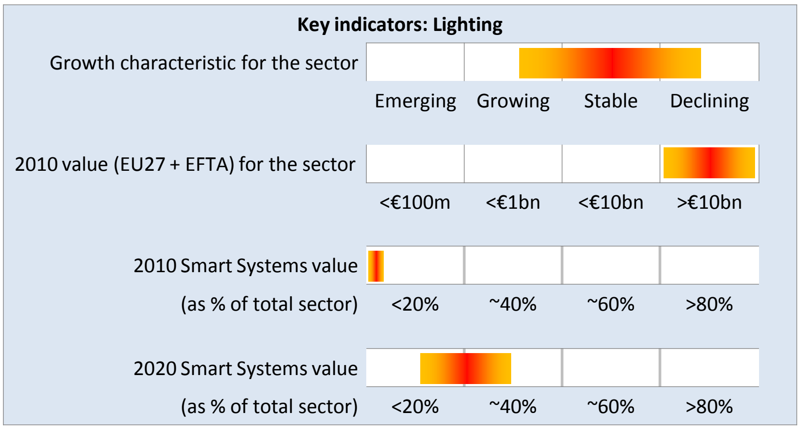
Sector forecast

The incandescent light bulb is being retired, and halogen bulbs will be next.

There is a window of opportunity for smart systems during this replacement period, as new functions offered by smart systems can enhance consumer willingness to invest in new devices.

However, once LED lighting is fully installed, the opportunity for smart systems will decrease because the next replacement bulb will not be needed for another 30-50 years (the lifetime of the LED).

Market predictions indicate moderate near term growth for lighting, followed by a period of lower market growth (or even decline). The emergence of OLED lighting may provide additional growth in the medium term.



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Quick links:

Sector overview | Lighting | Fossil fuelled generation | Oil & Gas exploration | Nuclear Energy | Renewables | Distribution, Storage & Use | EU Strengths & Research priorities

Smart Systems for Fossil fuelled generation

Overview

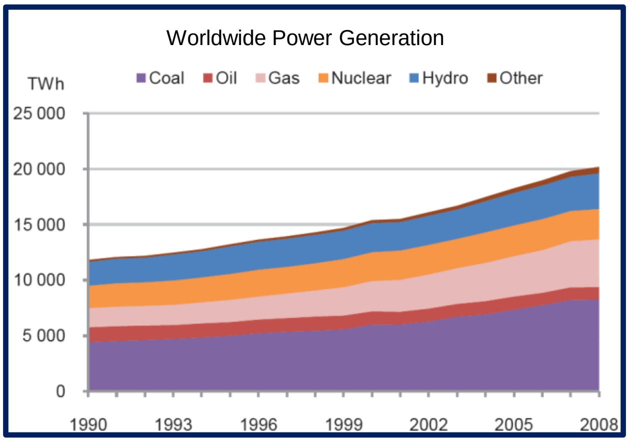
Global electrical power generation increased by 38% from 2000 to 2010, with the lion's share of new demand coming from developing countries in Asia.

While renewables have made significant progress in Europe, fossil fuels have been the primary vectors for overall increased generation with consumption of coal and gas up nearly 105% in Asia over the same period.

Coal and gas (particularly shale gas) are expected to continue with strong growth over the next 10 years, despite correlation to CO_2 release and global warming effects.

Opportunities for Smart Systems

- Optimized control of the combustion process to improve efficiency, reduce pollution.
- Smart control of co-generation.
- Harvesting from heat losses, and useable energy for other processes.
- Carbon Capture and Storage.



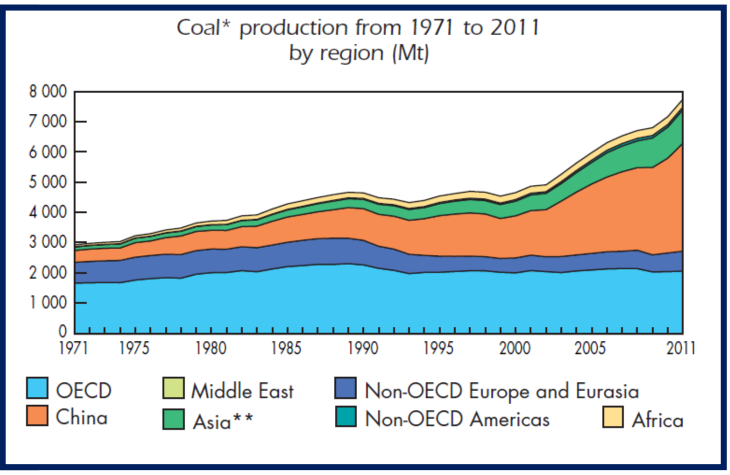
Source: IEA, 2010

Hurdles to be overcome

- Supercritical generation plants operate at high pressure and temperatures exceeding 600°C, requiring sensor systems for extreme conditions.
- Smart systems are needed for precise fuel feedstock characterization (i.e. humidity content, hydrocarbon content, mass flow).
- Exhaust gases are highly corrosive and require robust systems for monitoring effluents.

Applications

- EU dependency on imported gas will continue into the foreseeable future. Smart Systems must maximize the potential output of these resources through efficiency and adaptability in power generation.
- Efficiency of fossil fuelled generation plants increases significantly with higher operating temperature and pressure, providing opportunities for high temperature sensors and electronics based on materials such as AlN, SiC and GaN.
- Both optical and resonance based sensor systems can provide better control of the feedstock, the combustion process and the effluent gases. Robust systems are needed to operate in the challenging environments of power generation plants.
- Carbon capture and storage requires sophisticated Smart Systems for process control and monitoring.

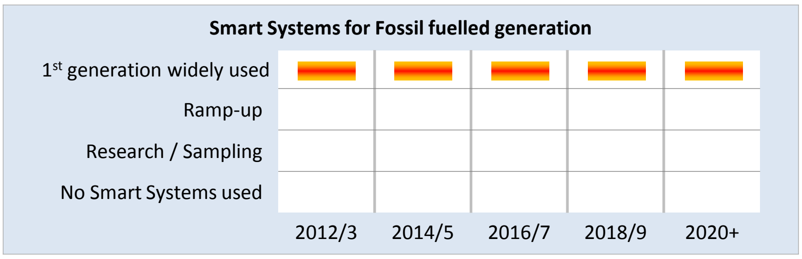


Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

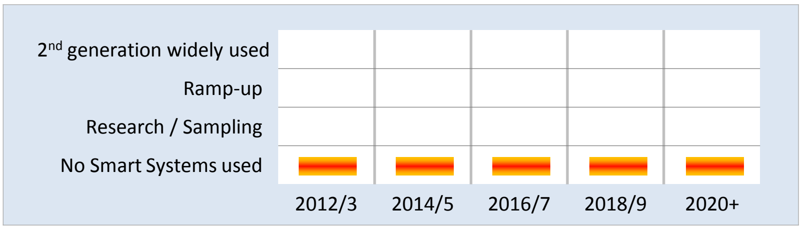
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Combustion control sensor measures CO/CO_2 and adjusts fuel/air to regulate combustion.



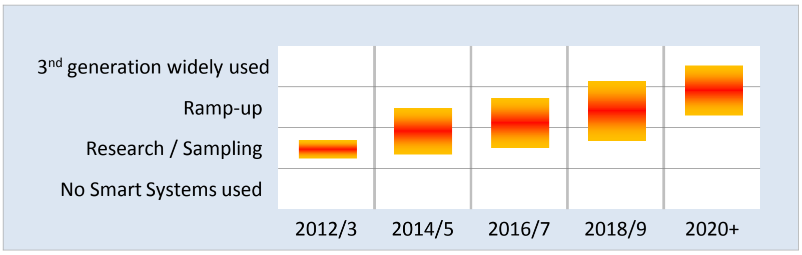
2nd generation Smart Systems are predictive and self-learning.

Fuel quality sensor systems differentiate between gas from the North Sea area and Russia and adapt the combustion profiles accordingly.



3rd generation Smart Systems simulate human perception/cognition.

Gather use information, including weather forecasts, predict schedule for generation. Particularly for smaller installations, and district co-generation.

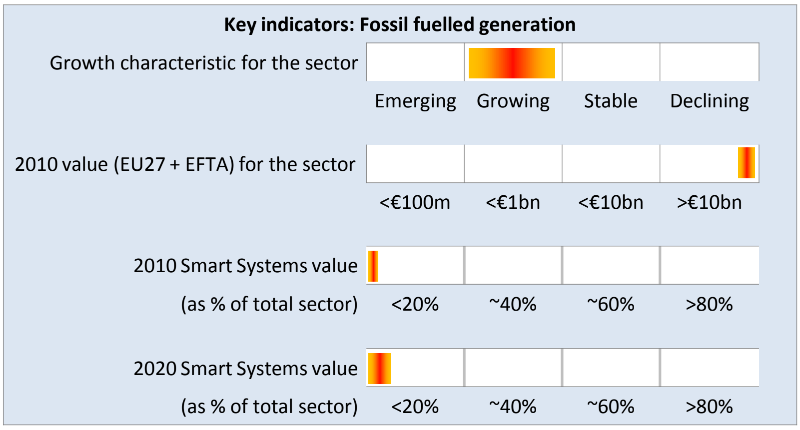


Sector forecast

Fossil-fuelled generation is still a growing sector and will continue to grow for many years into the future.

The adoption of Smart Systems, although a very small proportion of a very large sector, is, in absolute terms, a very large growth opportunity.

Carbon capture and storage will become a reality and the first implementations will be directly at the generation sites.



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Quick links:

Sector overview | Lighting | Fossil fuelled generation | Oil & Gas exploration | Nuclear Energy | Renewables | Distribution, Storage & Use | EU Strengths & Research priorities

Oil & Gas exploration

Overview

Fossil fuels satisfy 80% of the world's primary energy needs, and 77% of primary energy requirements in the EU.

Conventional oil and gas reserves have been largely identified and put into production. Advanced geological investigation is often performed under harsh conditions (deep sea offshore, Arctic).

Non-conventional reserves (shale gas, tight oil and coal gas methane) are in early stages of exploitation and present tough challenges.

Opportunities for Smart Systems

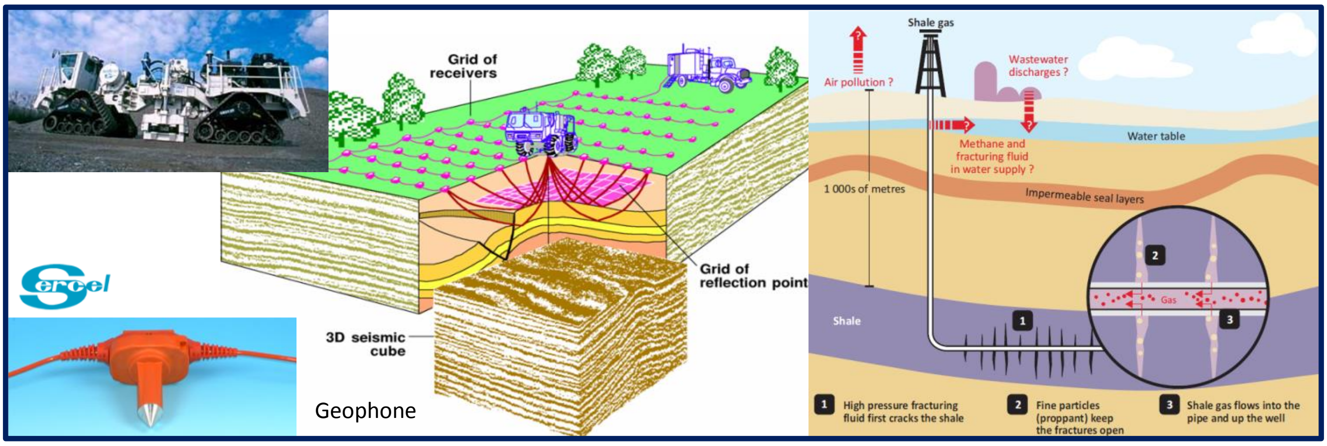
- Better information about subterranean formations will allow more precise well positioning. More accurate geophones should be coupled with additional sensing /imaging techniques.
- Hydraulic fracturing for shale gas extraction should be contained to the target strata to prevent contamination of aquifers. Sophisticated sensing systems are needed to monitor the fracturing process.

Hurdles to be overcome

- Higher sensitivity is needed for both exploration and exploitation, better sensors, but also better software to eliminate interference.
- Down-hole sensing systems require high temperature, harsh environment capability, often coupled with remote communication.

Applications

- Shale gas exploration and extraction continues to gain momentum in North America, and activities have begun in Europe. Smart systems will successfully monitor the process for maximum results with minimal environmental impact.
- Detecting and limiting methane release into the atmosphere during gas mining (especially shale gas) will soon become a major environmental/political issue as global warming continues.
- Continued exploitation of older, partially depleted oil and gas fields such as in the North Sea will require improved technology for locating and extracting remaining resources.
- High temperature and high pressure down-hole sensors and smart systems are required for deep sea mining.
- Higher sensitivity geophone sensors with intelligent data treatment algorithms are needed for deep sea and salt dome exploration.



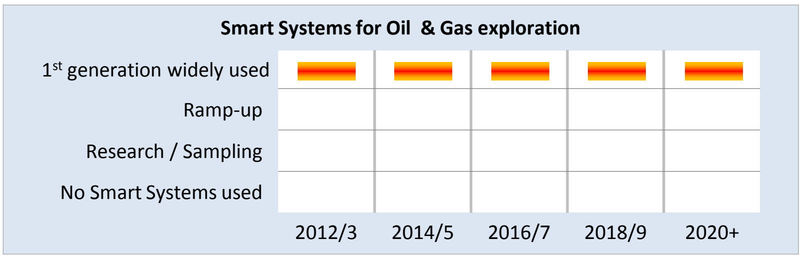
Source: OECD/IAE 2012 World Energy Outlook

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

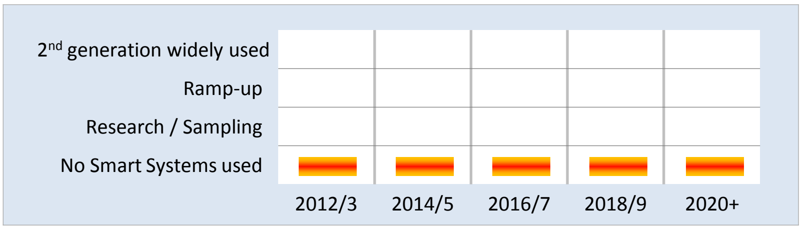
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Example: Geophone land based mapping system for oil reserve detection.



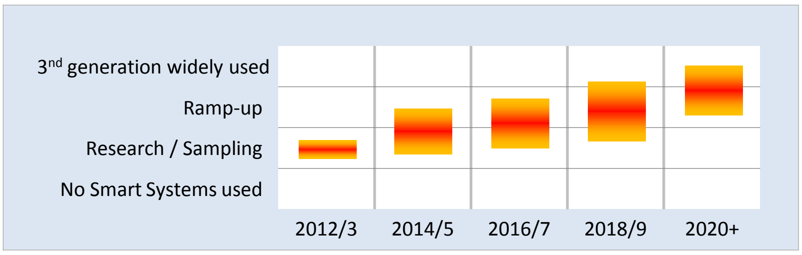
2nd generation Smart Systems are predictive and self-learning.

No examples as the complexity of typical problems requires 3rd generation technology.



3rd generation Smart Systems simulate human perception/cognition.

Autonomous robot (swarms), sub-sea, and airborne.

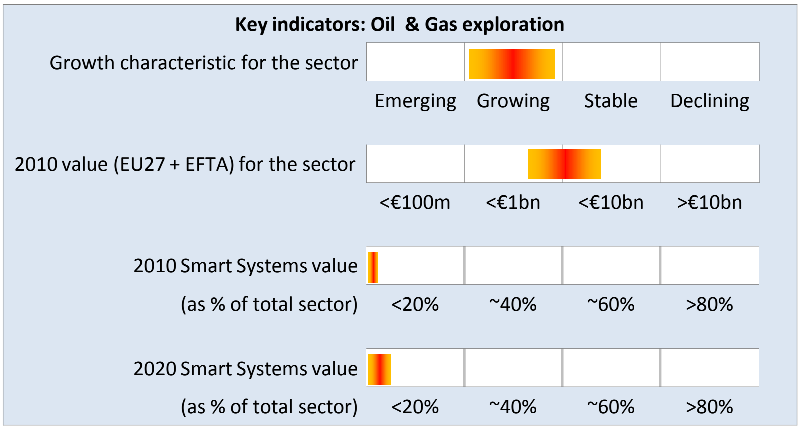


Sector forecast

Fossil fuels will continue to be the resource of choice for primary energy through 2030. Exploration requirements can only increase as the “easy to extract” resources are depleted.

The adoption of Smart Systems, although a very small proportion of a very large sector, is, in absolute terms, a very large growth opportunity.

Every developed country relies heavily on fossil fuels for transportation, and many countries are also tied for electricity generation.



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Quick links:

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Nuclear Energy

Overview

Nuclear energy requires the highest level of safety and security for error-free operation.

The large majority of active nuclear power plants have been commissioned in the 1970's and 80's, with relatively few new reactors since 1990.

Public sentiment against nuclear power influences public policy decisions following a crisis (plans for new reactors cancelled after Chernobyl, Japan halts reactors after Fukushima) but economics of energy continue to keep nuclear in the future energy mix of developing regions, especially China and India.

Opportunities for Smart Systems

- Nuclear plants originally built for a lifetime of 30-40 years will remain in service for 50-60 years, upgrades are required for extending service life.
- Decommissioning presents the challenges of decontamination, separation, transportation and storage of active materials.
- Disposal / storage of spent fuel waste.

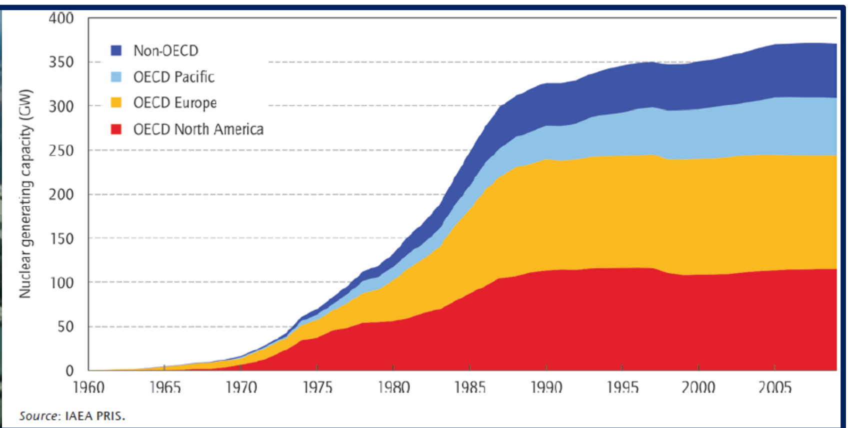
Hurdles to be overcome

- Radiation-hard sensors, electronic systems, communications and materials are required.
- Sensors and electronics that operate at extremely high temperatures
- False alarms need to be avoided.

Applications

- Overall, the EU relies on nuclear energy for 29% of total electricity generation*
- By applying new technology, such as efficient sensing and control systems, older generation reactors are now generating up to 10% more power output than their original maximum output rating.
- Next generation sodium reactors will require pressure, temperature, vibration, flow and radiation sensor systems that operate inside the core (500+°C) and transmit data wirelessly.
- Construction delays and budget overruns for 3rd generation reactors currently under construction demonstrate how safety and security issues can either make or break a new reactor introduction.

* 2008 data, source: OECD/EIA 2010

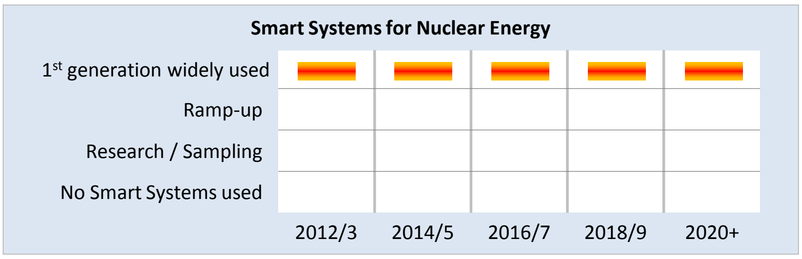


Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

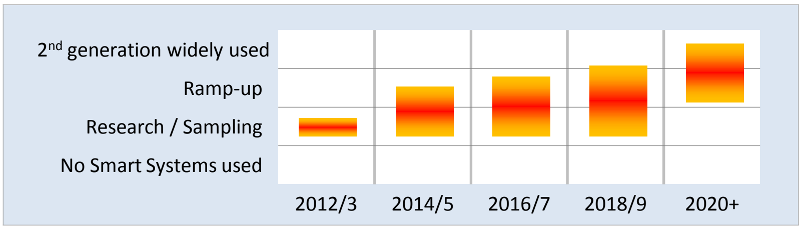
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Position/orientation of valves, pressure, temperature and flow sensors, etc.



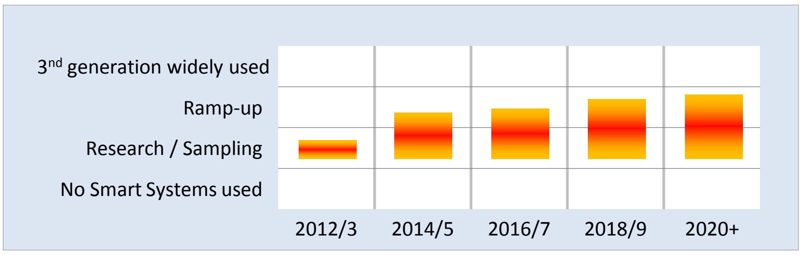
2nd generation Smart Systems are predictive and self-learning.

Monitoring and prognosis, particularly of structures.



3rd generation Smart Systems simulate human perception/cognition.

Autonomous robotic units for inspection, maintenance, repair, deconstruction



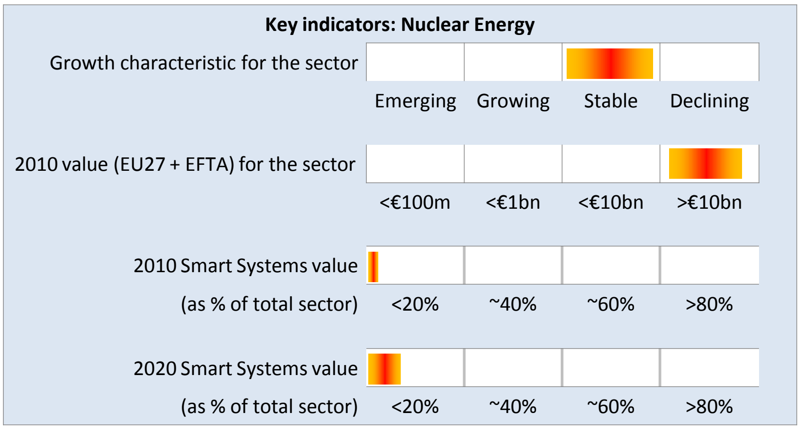
Sector forecast

Since the Fukushima accident of 2011, only 7 of the 40 previously planned new construction starts have actually broken ground, and only 9 out of 22 newly built reactors have actually been placed in service.

China, India and Russia continue to pursue their nuclear programs, while North America and Europe have put most of their programs on hold, or even closed definitively as is the case of Germany.

Decommissioning needs will increase significantly through 2020 and stabilize around 2025

Smart Systems are needed for Gen II upgrades, for Gen III reactor systems, for increased inspection (Health Monitoring) and also for conditioning the safe storage of spent fuel.



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Renewables

Overview

Renewables represent the fastest year-on-year growth of all energy sectors. However, the distributed nature of renewables presents additional challenges for seamless integration into the existing grid structure.

Smart systems will play an increasingly important role in providing successful implementation strategies for efficient and reliable renewable energies (hydro, solar, wind, biomass, geothermal, wave, tide).

Opportunities for Smart Systems

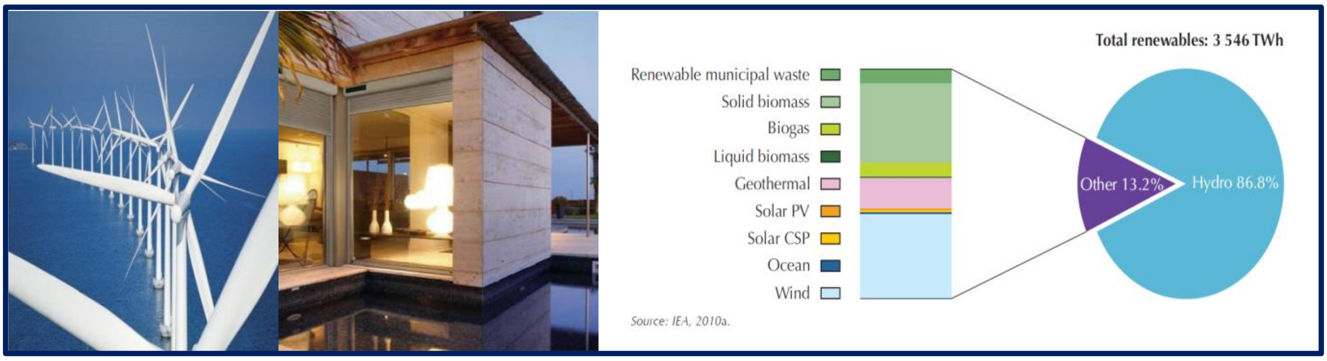
- Both wind and solar are highly variable, leading to instabilities in the grid. Energy management including storage will be key as the percentage of renewables increases.
- Power electronics coupled with intelligent sensing and control systems will be the cornerstones of future smart systems for renewables.

Hurdles to be overcome

- Power electronics need to be improved, there is a mismatch between the lifetime of the generator and the lifetime of the electronics in PV systems.
- Optimise the whole-life cycle impact.
- Concentrated solar generation relies on very high temperature operation, often beyond the range of most currently available sensing and control systems.

Applications

- Efficient monitoring of solar panels requires sensing at each panel, not collectively. Individual mini-inverters with multi-parameter sensing and network connectivity are well adapted for solar farm management.
- Integrated health monitoring for wind turbines should combine multiple inputs to define the health status of the turbine and select appropriate operating conditions.
- Planning systems currently used to predict energy demand and plan energy production in generation plants will be adapted to treat regional renewable generation as if it were a single generation plant . Algorithms will rely heavily on inputs from smart sensing systems.
- Off-grid autonomous systems will become less expensive to install and operate than grid connected systems (example: autonomous solar powered window blinds pictured below)
- Robust, highly accurate sun trackers for concentrated solar installations

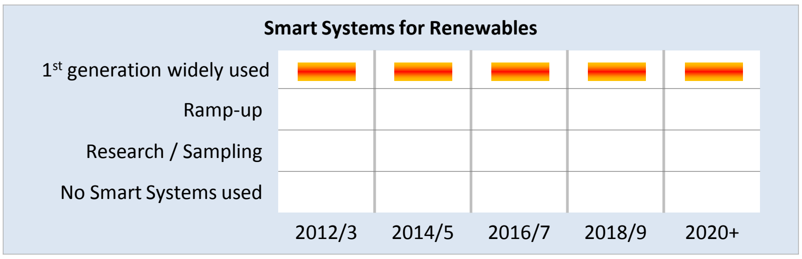


Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

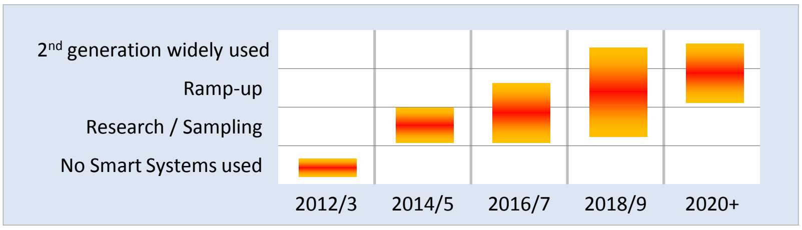
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Currently local control of PV orientation, regulation of wind water turbines & reduction and prognosis of gear box wear. Control of stand-alone systems.



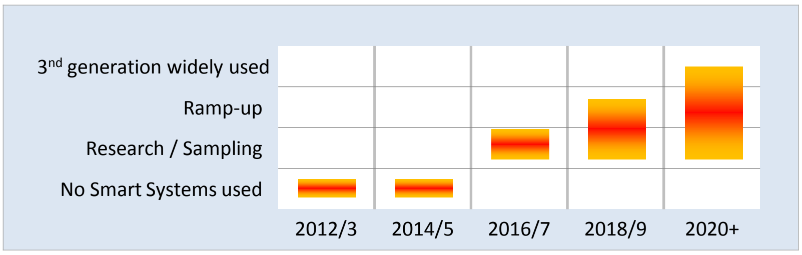
2nd generation Smart Systems are predictive and self-learning.

Turbine monitoring systems are able to detect bearing degradation in early stages and schedule preventive maintenance before failure.



3rd generation Smart Systems simulate human perception/cognition.

Integrated monitoring and control systems for wind turbines take into account many factors to determine an overall operating profile (i.e. normal, reduced speed, damaged, full stop).



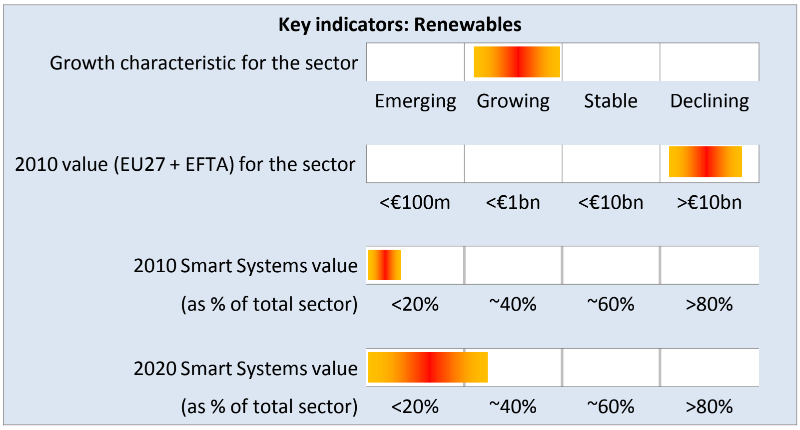
Sector forecast

Renewables are expected to grow at 7,6% per year through 2030.*

Advances in technology will continue to drive down the cost of renewables, with photovoltaic electricity generation estimated at 0.075€/kWh in 2020.** Local storage will likely be required for larger solar and wind installations to alleviate grid perturbations, and smart systems will be an important part of the solution.

Smart Systems will contribute to the autonomous operation of renewable installations, reducing service needs, maintenance time and overall cost of operation. The service industry applied to renewables will provide new opportunities for creating value with innovative Smart Systems.

*BP 2013, Energy Outlook 2030
**Clefs CEA 2013



The indicators above are shaded to reflect uncertainty

Quick links:

Sector overview | Lighting | Fossil fuelled generation | Oil & Gas exploration | Nuclear Energy | Renewables | Distribution, Storage & Use | EU Strengths & Research priorities

Smart Systems for Energy Distribution, Storage and Use

Overview

Energy distribution traditionally flows from centralized production/generation to distributed consumption. While fossil fuels can be easily stored, electricity storage for later use is problematic and today is not practical on a large scale aside from pumped hydro in mountainous regions.

The future development of renewables will require bi-directional distribution of electrical energy, with significant storage requirements to offset variability.

Energy use is predictable, and peak consumption periods will require measures to reduce non-critical use during these periods for peak shaving.

Opportunities for Smart Systems

- Grid management systems which can detect signs of weakness or instability before the onset of faults.
- Safety of pipelines, pylons, underground cables. Health monitoring of the infrastructure. Security of the network, and nodes like transformers, which contain hazardous chemicals. Security of networks against lightning, flood, physical and cyber attack.

Hurdles to be overcome

- Energy storage technology for conversion of electricity with high efficiency.
- Diagnostics and prognostics for energy storage devices. Extended life and recyclability of storage devices.
- Secure grid and data systems to avoid cyber attacks.

Applications

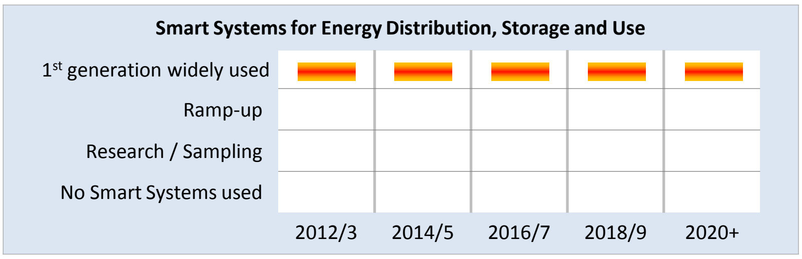
- Accurate weather and usage data fusion for development of models to predict generation requirements.
- Diagnostic of power transmission lines with remote, automated systems.
- Solar farm management and control systems based on intelligent sensing and control.
- Large scale storage systems based on either electrochemical, hydrogen or thermal storage.
- Methane detection systems for monitoring of gas infrastructures (estimated 3% system loss on average)
- Local energy management systems to adapt consumption according to requirements – the Smart Home

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

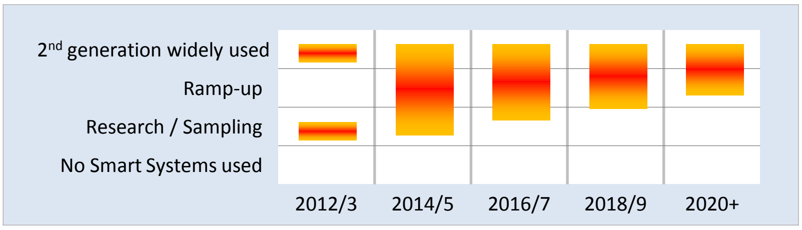
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Charging systems for electric vehicles charge until the “full” energy level is reached, then stop charging to avoid damage to the lithium battery.



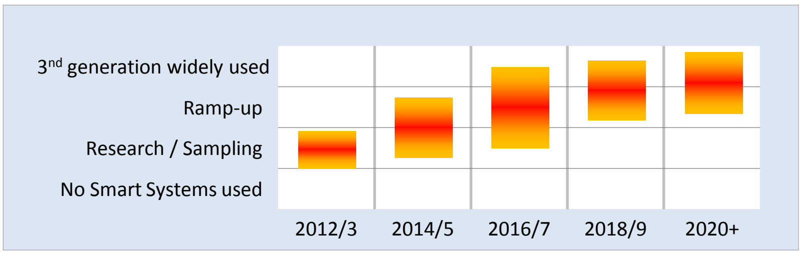
2nd generation Smart Systems are predictive and self-learning.

Charging systems which only charge during off-peak periods and will even discharge (re-sell) back into the system.



3rd generation Smart Systems simulate human perception/cognition.

Internet Of Things: When devices collaborate over their energy use/provision/supervision



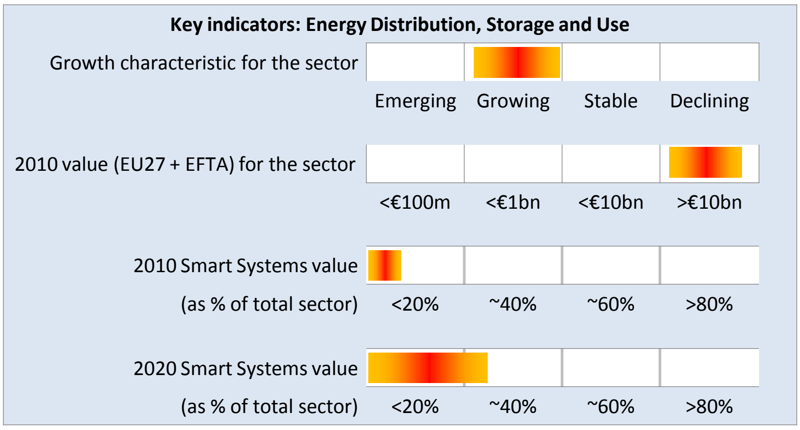
Sector forecast

In the short term, continued expansion of solar and wind will put pressure on the operational requirements of the grid, pushing the need for a smart grid.

Large scale storage remains limited to hydro pumped storage.

Gas use will continue to increase with LNG distribution and biogas competing with regional gas production.

In the middle term, hydrogen and other storage methods will be commonplace, particularly if hydrogen can be re-injected directly into the gas network.

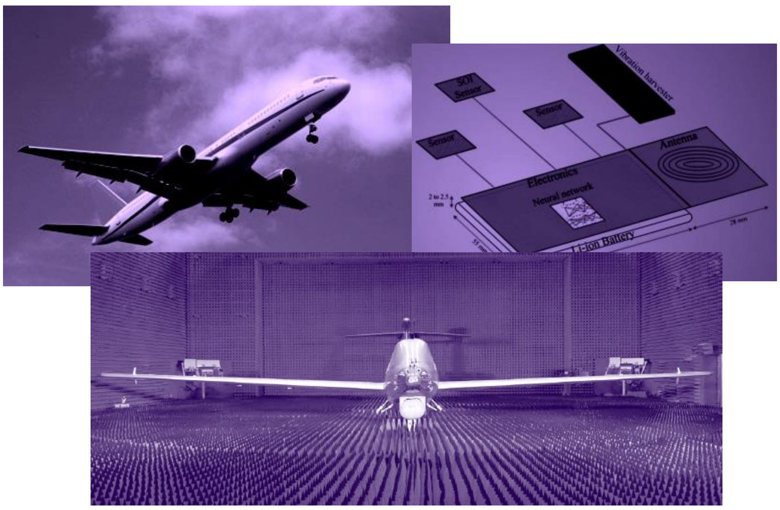


The indicators above are shaded to reflect uncertainty

Quick links:

Sector overview | Lighting | Fossil fuelled generation | Oil & Gas exploration | Nuclear Energy | Renewables | Distribution, Storage & Use | EU Strengths & Research priorities

SMART SYSTEMS FOR AEROSPACE



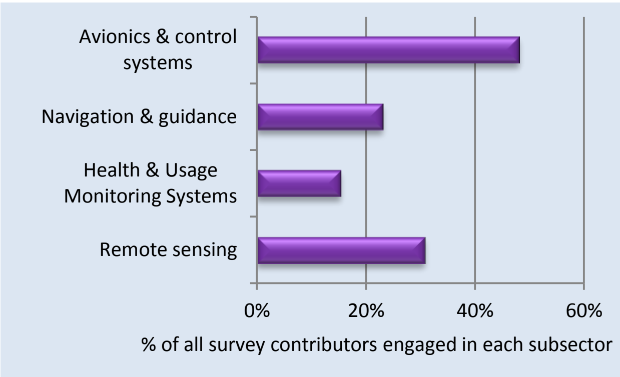
Smart Systems for Aerospace

Overview

The demands for precision, low mass, energy efficiency and utmost reliability make Aerospace a fundamental driver for high technology developments.

Smart Systems bring the potential for the elimination of human error in control, guidance and navigation, and for the continuous monitoring of safety-critical structures and mechanisms.

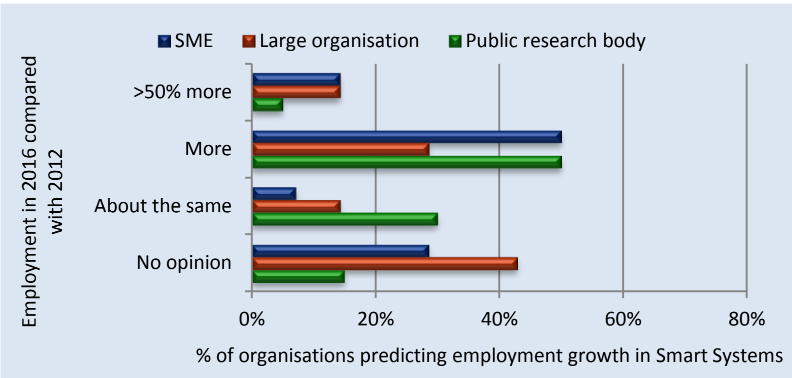
Airbus – *Eads/Thales*



Profile of subsectors

52 Smart Systems providers including 28 companies, representing the supply chain from research through to market servers, revealed clear distinctions between subsectors (illustrated left).

An examination of the percentages, which total 117%, reveals there is little overlap between these subsectors in terms of the engagement of organisations, but expert discussion revealed strong technology and operational synergies between the categories.



Growth prospects: Organisations

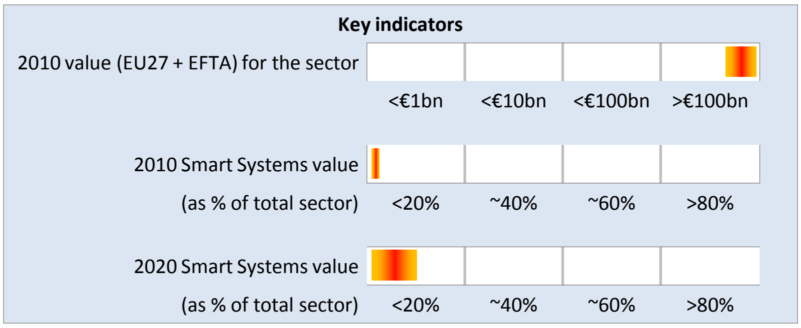
Of the Smart Systems providers surveyed, the great majority forecast employment growth, with a significant proportion of SMEs and large companies predicting headcount increasing by more than 50% by 2016 (illustrated left).

A similar picture emerged for growth in financial terms.

Growth prospects: Whole sector

European aeronautics is a profitable and growing manufacturing sector.

It numbers over 80,000 companies including a significant share of SMEs. It provides highly skilled, sustainable, long-term employment - in 2009 it supported 468,300 highly skilled jobs and generated a turnover in excess of €100bn. Smart Systems account for 9% of this, but could rise to ~15% by 2020 with next generation aircraft.



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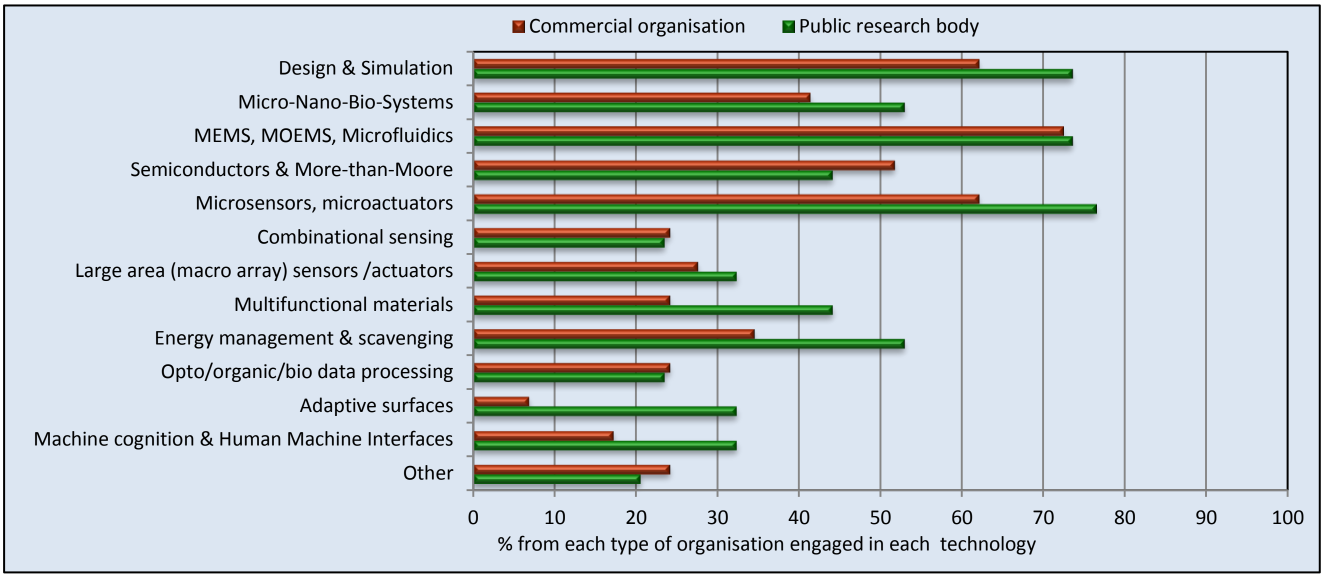
Underlying technologies



Aerospace companies reported three front-running technologies respectively: Microsensors & Microactuators, MEMS, and Design & Simulation. These are followed by Semiconductors & More-than-Moore technologies and Energy scavenging.

A higher proportion of Public research bodies report undertakings in Multifunctional materials, than that being taken up in commercial applications. There is a similar situation regarding Adaptive surfaces.

Taking into account their potential for innovation in this sector, a key issue for support action should include:

- Developing heterogeneous integration of smart sensors, embedded software and long life operating nanoelectronic-based systems for safety compliant applications.
- Encouraging the exploitation of Multifunctional materials and Adaptive Surfaces in the Aerospace sector.

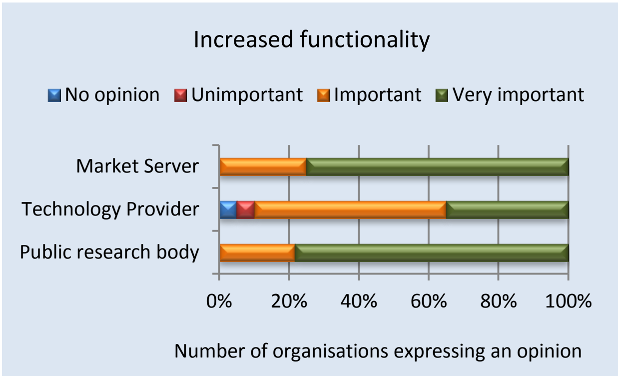
Drivers and barriers

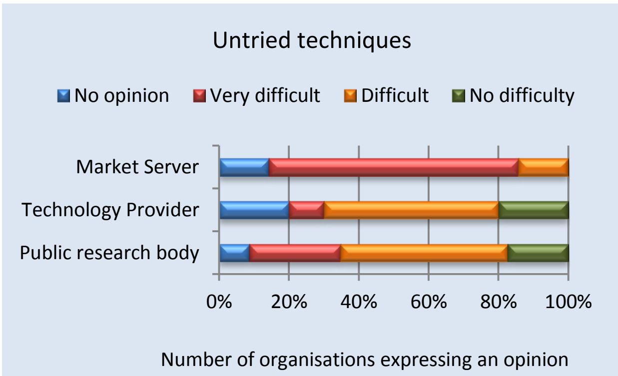
The survey of Smart Systems providers to the Aerospace sector rated "Increased Functionality" as the most important driver compared to, in descending order, Increased Reliability, Reduced Cost, New Markets, Global Competitiveness, legislative drives, and Simplicity in Use.

The most obstructive difficulty reported was "Untried Techniques". This is instructive as the Increased Functionality Driver is most likely to be satisfied by Untried Techniques.

Accordingly, action should therefore be considered to mitigate the risks entailed in the uptake of Smart Systems for example by:

- Encouraging tighter inter-disciplinary R&D.
- Securing a complete EU value chain for Smart Systems compatible with reliability, safety, security requirements and low volume production.
- Supporting the development of holistic simulation tools with coverage from concept, through manufacture to in-life service, that allows fast insertion of technologies and their qualification.





The sector in more detail

Civil aviation is vital for European society and its economy.

It fulfils societal needs for suitable and sustainable mobility of passengers and goods over longer distances. It enables Europe to be connected to other continents and underpins Europe's position as a geopolitical power.

Aviation generates wealth, employment and economic growth for Europe. It contributes significantly to a positive balance of trade through export, provides high added value and highly skilled jobs and ensures European self-reliance.

By fostering Europe's knowledge economy, and honing the community's competitive technological edge, the aviation sector contributes significantly to the European Horizon 2020 Strategy.

The air transport sector supports 8.7 million jobs overall, contributing nearly €600bn to GDP through direct and indirect mechanisms.

Europe has 701 commercial airports and 448 airlines with approximately 6,600 aircraft in service. European air traffic is managed by 45 air navigation service providers.

In 2010 the European air travel sector saw 606 million passengers carried on 7.9 million flights, creating significant rewards for the tourist industry and immense efficiencies for business travellers.

In addition to civil aviation, Europe is a strong player in the global Space industry, the European Space Agency (ESA) budget for 2013 totalling some €4.28bn, which includes a major element from the European Commission.

Europe's most visible space activities are concerned with immense internationally-connected projects such as the International Space Station, major launch capabilities, Europe's own independent satellite-based navigation system Galileo, and the European Earth observation programme Copernicus.

Galileo and Copernicus both promise benefits to citizens and the economy, and will interface with and enhance Smart Systems enabled products and services throughout every sector reviewed in this Strategic Research Agenda.

Beyond these major programmes, Europe's space interests also include a rapidly growing activity in nano-satellites and other highly miniaturised autonomous packages that depend vitally on Smart Systems technology.

The sector and its subsectors

In view of its central importance to the EU as described above, this chapter concentrates upon civil aviation, and four main topics:

- Smart Systems for Avionics and Control Systems.
- Smart Systems for Navigation & Guidance.
- Smart Systems for Health & Usage Monitoring
- Smart Systems for Remote Sensing.

Consequent to the highly integrated nature of aircraft, there is inevitably an overlap between these categories, and an inter-relationship between how the systems are designed and manufactured, and how they operate together in service.

Benefits of Smart Systems

In the first instance, on-board electronic systems enable the crew to control the aircraft, navigate, communicate and accomplish their mission safely, but many subsidiary functions are also essential to the air transport system, including also airports, to facilitate the movement of people and goods.

The key benefits expected from Smart Systems in civil aviation are therefore:

- Precision in navigation and flight control.
- Operational availability in severe conditions.
- Robust, high performance, globally competitive solutions to the issues of increasing traffic, fuel efficiency, and low CO_2 footprint/emissions.
- System upgradeability for long life operations.
- Reliability, safety and security.
- Integration into multi-modal transport systems and logistics.

Technical Challenges

The related challenges in which Smart Systems could contribute to *European aviation Vision 2020* and *Flightpath 2050* are:

- High performance sensors for navigation and remote sensing for more demanding air traffic in all conditions.
- Smart Systems to include high connectivity communications to on-board operations.
- Electronic systems to operate in harsher environments, for example icy environments, and to counter the issues of thermal constraints due to the tight proximity of new generation components, and the thermo-mechanical resistance of lead-free packaging and assembly.
- Developments to cope with the ageing of technologies and electronic components developed for consumer and short product lifetime.
- Ensuring that Smart Systems and their enabling communication network shall be robust to intrusion, as the air transport system requires a fully secured global high bandwidth data network, hardened and resilient by design to cyber-attacks.
- The implementation of firm controls on the Smart Systems and components supply chain.
- Smart Systems solutions to enable e European aviation to stay globally competitive.
- The development of stringent qualification and certification for advanced technology as required by customers or agencies.

The Advisory Council for Aeronautics Research and Innovation in Europe (ACARE) produced in September 2012, a detailed SRIA which provides a research and innovation roadmap to reach the goals highlighted for each challenge in Flightpath 2050.

The roadmap concerns the priorities for aeronautical and air transport research and innovation and the related public policy issues to support these priorities. This roadmap is in three time scale: short term to 2020, medium term to 2035 and long term to 2050

This EPoSS SRA, focussing solely upon Smart Systems deals with the short term, as defined by ACARE, and prepares the enabling technologies for the medium term.

Introduction of Smart Systems

Sensors and miniature Smart Systems have been enablers of improvements in safe aviation for some years. New opportunities based upon three generations of Smart Systems are illustrated here:

- The concept of intelligent skin is to distribute a very large number of sensors on the surface of an aircraft to measure its local physical characteristics.

  Smart Sensors bring the possibility to multiply the number of measurements without increasing number of cables and consequent increases in weight and needs for management.

  A 1st generation Smart System can combine as many different transducers as necessary; at least one microcontroller to manage the measurements; enough memory to store the needed information; a subset of energy management, recovery and storage (battery or scavenger); and a network interface to communicate. Autonomous wireless devices will avoid the necessity for holes or trunking in the aircraft structure.
- A 2nd generation of Smart Systems will add the capability self-calibrate the sensors, actuators and electronic components against parameter drift and ageing effects.

  Sophisticated real-time diagnosis analysis will predict the need for repair or Integrated Modular Avionics changes, and the implementation of safety mechanisms.
- The aircraft instruments that use a gyroscope are the attitude indicator, the heading indicator and the turn coordinator. They have much higher accuracy than those in cars or in smart phones. Such inertial sensors could be combined with GPS through high grade 3rd generation Smart Systems to provide autonomous navigation.

European position

The European aviation industry is strongly competitive, delivers products and services worldwide and has a share of more than 40% of the global market.

While the number of flights is increasing, the European air transport system needs to operate seamlessly allowing manned and future unmanned air vehicles to safely fly in the same airspace.

Europe's aviation industry has an exemplary safety record. Lessons have been learnt from long experience, and the implications of increased traffic and shared airspaces will in part be mitigated through new sensors and Smart Systems technologies that fully utilise Europe's accrued experience. The ability through Smart Systems to access and implant deep safety experience represents an enormous and vitally advantageous opportunity for Europe.

The objectives for European industrial leadership have been defined by the Cleansky Joint Technology Initiative and the ACARE Advisory Council for Aeronautics Research and Innovation in Europe.

They concern the continuous development of new technologies, new platforms and their flight test, developments in efficiency and the manufacturing process, together contributing to seamless integration of the certification of aviation products.

Technology capabilities and a robust supply chain are needed in Europe for aviation, which ultimately benefits all European sectors.

Research overview

Aircraft and their related transport infrastructure are expected to stay in service for perhaps decades. Consequently the research community and industry serving the aerospace sector need to break away from the trend to develop short lived technologies targeted for consumer applications.

Some of the research priorities allied to Smart Systems are:

- Smart, lightweight, low cost, long life, reliable sensor and multi-sensor systems.
- Miniaturised Smart Systems to combine Galileo with GPS for autonomous navigation and adaptive autopilots.
- Smart, adaptive, high data rate links to expand ground-to-air communications.
- Low profile or conformal active and adaptive antennas.
- Communication and critical electronic systems resilient to failure and cyber threats.
- Smart Systems packaging allowing greater integration whilst providing better protection from heat and electromagnetic interference.
- Smart Health and Usage Monitoring Systems, with energy autonomy.

The technical challenges need to be addressed in ways that resolve or are compatible with the following more general yet pressing issues:

- Overcoming the "death valley" between research and commercial exploration.
- Assuring a properly accredited and traceable manufacturing supply chain entirely within Europe.
- Overcoming the "cost of qualification" issue: Why pay €200k for aerospace qualification, when the technical gain may be only 100 g or 10 mW? This is €2m/kg, way in excess of costs in other sectors.

References

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US NextGen Avionics Roadmap
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Value of electronic equipments for European aerospace turnover
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European Space Agency
www.esa.int

European Commission : European Space Policy
http://ec.europa.eu/enterprise/policies/space/esp/index_en.htm

Smart Systems for Aerospace: EU Strengths & Research priorities

Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Sector as a whole	•Big established companies •Materials knowledge •Strong research base	• Supply chain has elements outside Europe	•Increased requirements on safety, airworthiness & certification	•Asian capabilities growing •Lead free assembly for consumer does not apply to aerospace profile
Avionics & Control Systems	• World leading in smart cockpits •Active development and deployment of Unmanned Aerial Vehicles	•Weak links along the supply chain regarding failure mitigation	•Use Smart Systems to access and implant Europe's deep safety experience into Avionics and Control systems	•Aircraft communications (passengers, air to air and air to ground) leading to security concerns •Fast growing UAV expertise and investment in the US
Navigation & Guidance	•SESAR (Single European Sky Air Traffic Management Research) •Competence in satellite based guidance	•Differences at National levels, so problems and political responsibilities are not shared	•Galileo high performance satellite •Multimodal travel	•US develops NextGen air control capabilities management related, •SESAR does not address technology, NextGen does
Health & Usage Monitoring Systems	•Good historical experience of the behaviour of systems •Well controlled maintenance services by major air flight companies	•Need to solve problems of energy autonomy •Low energy networking •Regulation needs to be concurrent with technology capabilities	•Miniaturised HUMS can retrofit to global fleets •Connectivity to smart IT •Better capability of maintenance teams •Cost saving leverage in maintenance	•Level of regulations from outside Europe •Poor spectrum management •Self-specification/ certification/ over-certification
Remote Sensing	•Deep history in some fields •Low power but high capability computing	•Duplication of work in other sectors because of segmentation of industries	•Meta-materials for new sensors •Harness the increasing availability of computer power	•National inter-operability, agreement can cause delays

Sub-sector	Priority actions	Longer term actions
Sector as a whole	•Gain EU autonomy (IPR, manufacturing and supply chain) on all required core technologies •Smart Systems for reduced carbon footprint and faster travel: Modular optimised Power management allowing global weight reduction	•Insertion of reliable smart technologies with low cost qualification: New and safer designs while reducing the cost of certification •Technology integration into ageing aircraft
Avionics & Control Systems	•Research to link to cognitive sciences for pilots and remote controllers •Monitoring of pilot health and capability •Interconnection between on-board and on-ground information •High bandwidth connectivity in cabins with Ka-band satcom	•Network security and integrity •Cyber attack
Navigation & Guidance	• High grade Pressure and Inertial Smart Systems • Low footprint and low power consumption high precision Galileo/GNSS Smart Systems • Embedded Atomic clock for GNSS precision • New packaging standards appropriate for Smart Systems: System in Package (SiP) Heterogeneous 3D integration • New thermal management technologies regarding hot spots in integrated assemblies	•Long-life reliable and stable smart sensing and enabling nano-electronics •Hybrid and multimodal sensors •Fast diagnostic and exchange capabilities, exact failure predication •Cognitive functionality, by link to human sciences
Health & Usage Monitoring Systems	• Energy autonomy and miniaturisation •Optimisation of placement and integration •"Ultra reliability" (Ahead of the subjects to be monitored)	•On-board and remote system-wide monitoring •Smart materials and structures
Remote Sensing	•Detection and localisation in complex environments •Slow small UAV detection by ground based radars	•Risk analysis, definition of "small events" and "critical events" •Ethical, acceptability and security issues

Quick links:

Sector overview | Avionics & Control systems | Navigation & Guidance | Health & Usage Monitoring Systems | Remote sensing

Avionics & Control systems

Overview

Avionic equipment, including control, monitoring, communication, navigation, emergency, radar and anti-collision systems is most evident on the flight deck, but with nodes distributed around the aircraft.

The topic figures strongly in the Single European Sky ATM Research (SESAR) initiative in Europe and the Next Generation Air Transportation System project (NextGen) in the US. Accordingly, the potential for Smart Systems in navigation, guidance, monitoring and remote sensing is reviewed within dedicated subsectors of this chapter.

Ancillary to these primary avionics applications, there are also vitally important roles for Smart Systems in flight recorders and other emergency, safety and rescue systems, and in cabin equipment and environmental controls.

Automated pilot assistance techniques, such as automatic stability systems, already exhibit smart behaviour, but are essentially software routines added to the computer systems at the heart of fly-by-wire technology.

But further to all the above, something is happening that will revolutionise aviation, and drive R&D in Smart Systems: the UAV (Unmanned Aerial Vehicle) and the ground/air/vehicle combination, UAS (Unmanned Aircraft System).

Such drones – with 30,000 predicted to be flying worldwide by 2020 – will accelerate the development of light, efficient, reliable Smart Systems. This sharp impetus will undoubtedly spin off into significant Smart Systems enhancements, and supply chain stimulation, in sectors far removed from Aerospace.

Airbus A340-300 Fuel Panel – *© swiss_a320 flickr.com*

Opportunities for Smart Systems

- Potential to supplement (not replace) conventional flight recorders with miniaturised Smart System event recorders distributed around the airframe.
- Smart enhancements to life-saving and rescue equipment.
- Safe systems for the unskilled operation of small/micro UAVs
- Smart separation assurance & control for UAVs, singly, in combination, and in airspace shared with piloted aircraft.
- Autonomy & decision making Smart Systems to compensate for latency (time delays) occurring in the long-range remote control of UAVs.

Hurdles to be overcome

- The design and development of Smart Systems for the UAV market needs to be as rapid as that for consumer products, yet needs to be qualified to stringent aerospace safety standards.

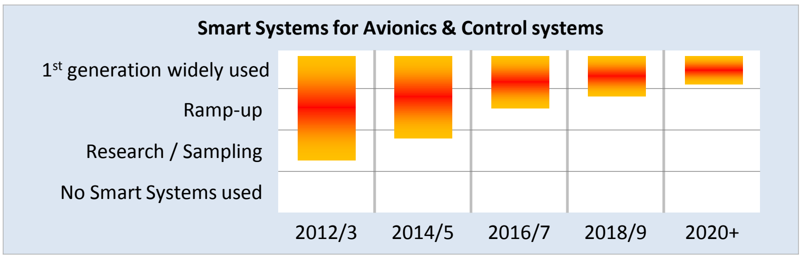
Autonomous Systems Technology Related Airborne Evaluation & Assessment programme (www.ASTRAEA.aero) – *© BAE Systems*

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

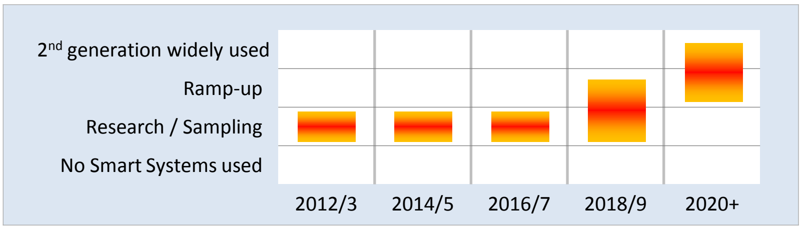
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Smart Systems techniques are already deployed within autopilot and automated pilot assistance systems.



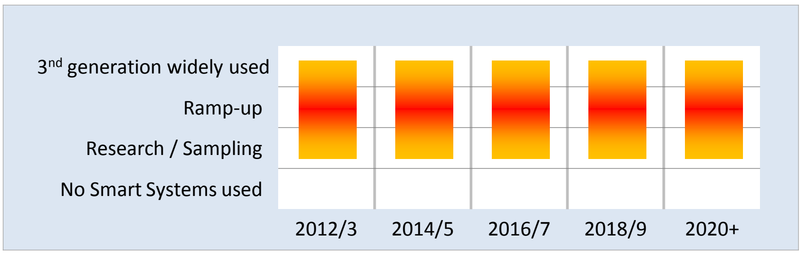
2nd generation Smart Systems are predictive and self-learning.

“Prediction” needs careful qualification in the realm of flight controls, but has strong potential in passenger handling and comfort.



3rd generation Smart Systems simulate human perception/cognition.

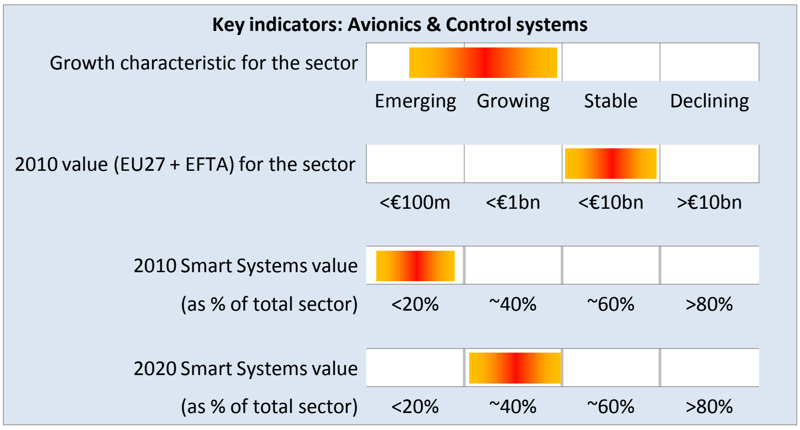
Small/micro UAVs are already in service for agriculture, pipeline security, road patrol, surveying and geo monitoring. The trend for the use of UAV technology in commercial aerial surveillance is expanding rapidly with the development of automated object detection.



Sector forecast

Avionic systems are already a very significant proportion of the cost of an aircraft, to which should be added the cost of the complementary ground infrastructure needed to keep aircraft flying.

The future Smart Systems value is a compound of increases in the density of air traffic, the rise of consumer aviation and UAVs, and the environmental improvements that are needed to maintain the acceptable viability of civil aviation.



The indicators above are shaded to reflect uncertainty

Quick links:

Sector overview | Avionics & Control systems | Navigation & Guidance | Health & Usage Monitoring Systems | Remote sensing | EU Strengths & Research priorities

Navigation & Guidance

Overview

Navigation and Guidance provide the position and direction on or above the whole surface of the earth.

These systems can use satellite data-links, ground-to-air VHF communications, inertial navigation, GPS/GNSS/Galileo navigation, and traffic alert and collision avoidance systems that can detect the location of nearby aircraft. Navigation systems calculate the position automatically and display it to the flight crew on smart map displays.

Airbus A380 flight deck - © *swiss_a320 flickr.com*

Opportunities for Smart Systems

- Developments within the SESAR programme focussing upon new European Air Traffic Control concepts, including 4D (3 spatial dimensions plus time) trajectory management and allied topics.
- Systems to correlate between GPS and on-board Smart sensors.
- Smart multimodal inertial sensors.

Hurdles to be overcome

- Need for integrity, high precision sensors and high availability in all conditions including the harsh environment of, for instance ice and storms.
- Avoiding or compensating for the ageing of components originally developed for consumer applications.
- The protection and security of GPS and Galileo systems.
- A higher performance and high reliability European supply chain for Smart Systems.

Applications

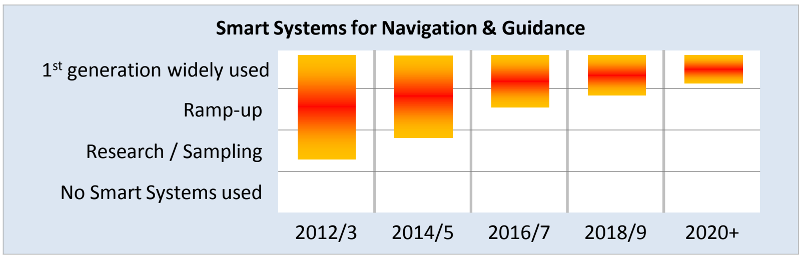
- Safety compliant on-board smart sensors for navigation, altimetry, velocity, and attitude to inform the pilot and to assist in the control of the aircraft.
- Smart Systems to improve the accuracy and safety of automatic landing under both normal and emergency conditions.
- SESAR comprises almost 300 projects in 16 work packages to develop and deliver the necessary operational and technical materials (specifications, procedures, prototypes, validation reports, etc) for the progressive industrialisation, deployment and operation of the Air Traffic Management systems needed to increase safety and efficiency as civil aviation continues to expand.
- Clean Sky is an aeronautical research programme to develop breakthrough technologies to significantly increase environmental performance, resulting in less noisy and more fuel efficient aircraft.
- Smart Systems can exploit this resources provided by satellite navigation systems (GNSS) put into place and maintained by the aerospace sector, but benefitting a growing number of economic sectors, in particular transport, telecommunications, agriculture and energy.

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature “generation” indicates increasing levels of “smartness” and autonomy.

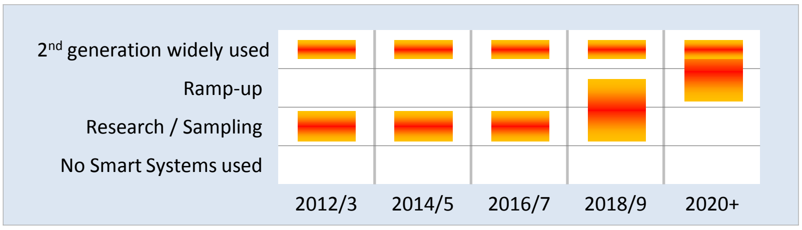
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

High grade MEMS sensors and calibration algorithms are embedded in aircraft guidance systems.



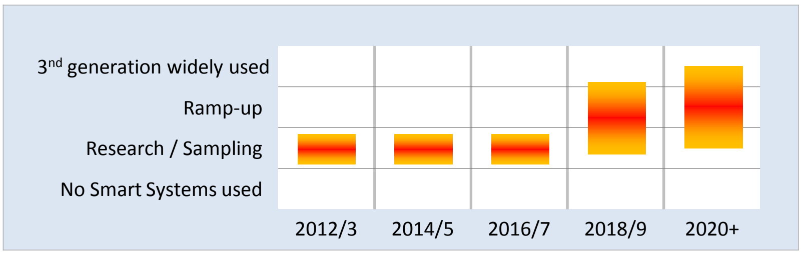
2nd generation Smart Systems are predictive and self-learning.

Collision avoidance systems need to extrapolate the tracks of aircraft.



3rd generation Smart Systems simulate human perception/cognition.

High grade inertial sensors combining GPS and high grade MEMS for autonomous navigation will progress towards digital Air Traffic Management.

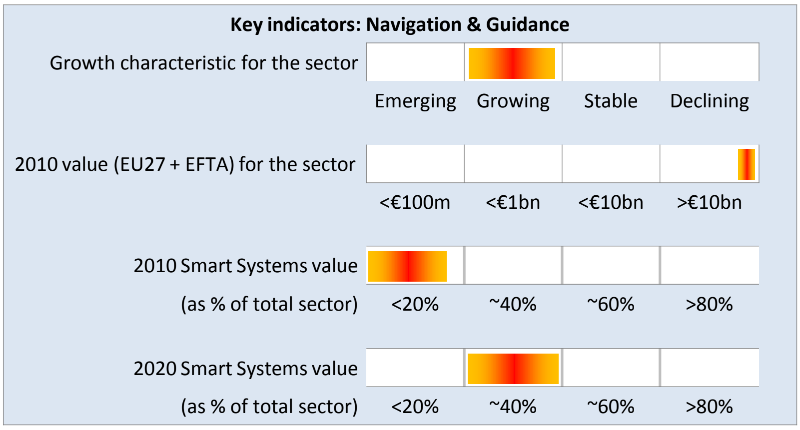


Sector forecast

Satellite navigation now determines the value of the Navigation & Guidance subsector. The adoption of Smart Systems, as a very small proportion of a huge business area, is, in absolute terms, a very large growth opportunity.

Besides the demands for more accurate gyros and accelerometers, developing the use of satellite navigation brings enormous benefits to the economy, society and environment beyond Aerospace.

These benefits are broken down into three main categories: direct benefits resulting from the growth of the space market, direct benefits resulting from the growth of the downstream market for GNSS-based applications and services, and indirect benefits resulting from the enabling of new applications in other sectors.



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Quick links:

Sector overview | Avionics & Control systems | Navigation & Guidance | Health & Usage Monitoring Systems | Remote sensing | EU Strengths & Research priorities

Health & Usage Monitoring Systems

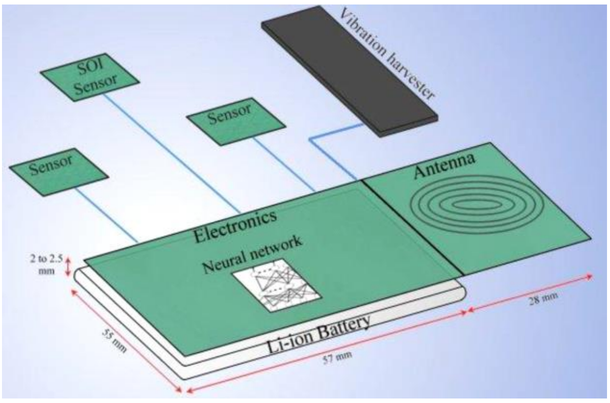
Overview

The availability of new sensors and of networks of autonomous communicating sensors, is the backbone of Health and Usage Monitoring Systems (HUMS) that in aircraft could provide better failure prediction, recording of related events, optimisation of maintenance operations including the logistics of valuable of spare parts, and even recording events during manufacture.

Smart Systems by their very nature provide the autonomy, miniaturisation, integration, networking and diagnostic/prognostic capabilities that are needed.

Opportunities for Smart Systems

- On-board electronic systems are becoming more complex and require better monitoring for safe flights and less downtime due to unexpected failures or unnecessarily tight maintenance schedules.
- Longer-life airframes can benefit from structural monitoring by networks of autonomous Smart Systems positioned throughout the aircraft and interrogated wirelessly during ground maintenance without undue disturbance.



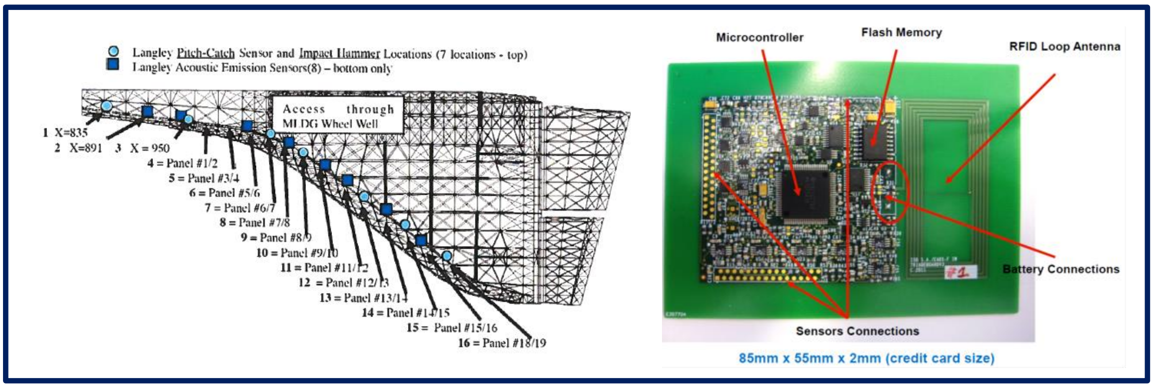
Hurdles to be overcome

- Wireless operation with energy autonomy.
- Development of analysis and prognosis models with an appropriate balance between accuracy and data density.
- Reliability of HUMS needs to exceed the reliability of the systems monitored.
- Virtual reality for repairer, look-up for parts and their expected parameters.
- Standardisation of interfaces and embedded software for prediction; certification of related solutions.

Applications

- Wing surface / skin monitoring and actuation.
- Diagnosis and prognostics both for on-board electronics and for new power electronics and batteries.
- Preventative maintenance when the damage is minor increases the aircraft mean time before failure.
- Early connection to ground servicing maintenance schedule and field failure reporting.
- Collecting and distilling human experience, and the behaviour of the structure and the avionic systems.
- Acquiring data relevant to pollution, risks (chemical risks e.g.), and reliability, end of life.

The figure below shows embedded sensors in the Endeavour space shuttle and a design from the EU FP7 TRIADE programme providing technology building blocks and fully integrated prototypes to achieve power generation, power conservation, embedded powerful intelligence data processing/storage and energy management for structural health monitoring in aeronautical applications.

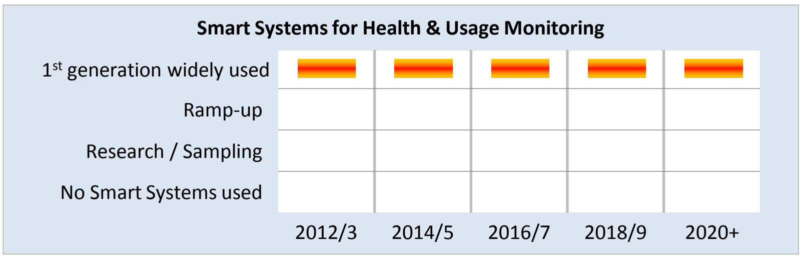


Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

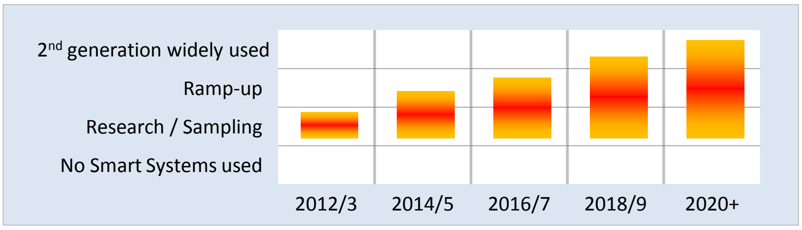
1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

Aircraft already include some energy scavengers with local recorders or wireless sensors.



2nd generation Smart Systems are predictive and self-learning.

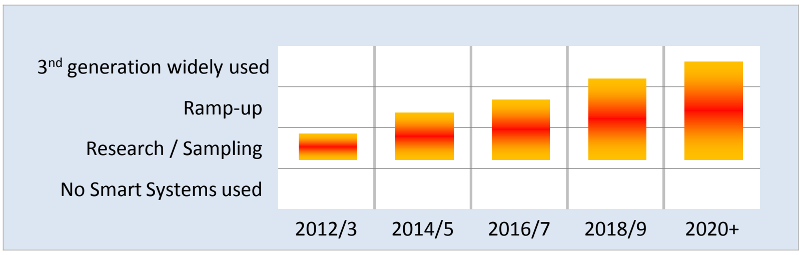
Smart skin for monitoring and prognosis, particularly of structures and of electronics, using smart sensor networks.



3rd generation Smart Systems simulate human perception/cognition.

The provision of prioritised alarms to pilots.

Autonomous inspection, maintenance, repair and deconstruction robotics.



Sector forecast

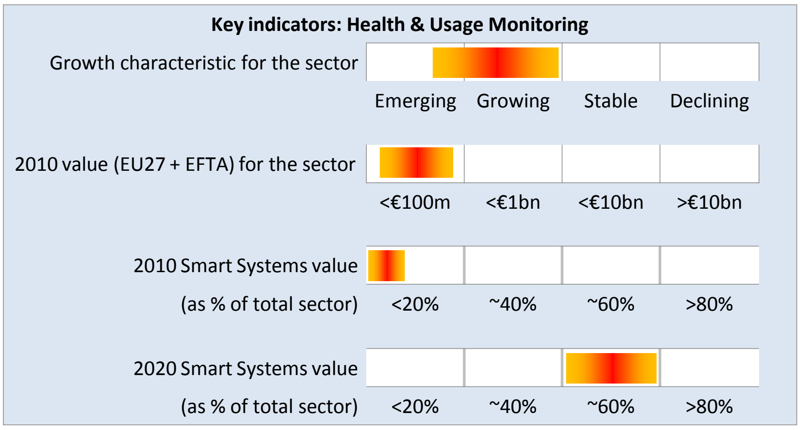
Autonomous Smart Systems and networks are fundamental enablers for HUMS.

Implementable and certified solutions will result in a large and beneficial impact on life cycle and operational costs, including maintenance.

Very large growth opportunities:

- Extending the life of airframes experiencing more arduous and numerous flights, while allowing lighter weight, higher performance and less downtime.
- Understanding the behaviour of structures using new materials.

A study from Goodrich stated: "Structural Health Monitoring shows great potential… …inspections are currently about 25% of the Life Cycle Cost of an airline".



The indicators above are shaded to reflect uncertainty

Quick links:

Sector overview | Avionics & Control systems | Navigation & Guidance | Health & Usage Monitoring Systems | Remote sensing | EU Strengths & Research priorities

Remote sensing

Overview

Remote Sensing gains qualitative and quantitative information about distant objects and conditions without coming into direct contact.

Satellites observe the Earth over wavelengths from Extremely Low Frequency through microwave, infra red, visible, ultra violet and up to x-rays. They are also sensitive to gravitational and magnetic fields and use radar and lidar (LIght Detection And Ranging) imaging, so they can collate very comprehensive data sets.

Just as the space industry learned from aviation's early use of radar and thermal imaging, now aviation is benefiting from space, to extend the ability of aircraft to react to hazards along the flight path.

Opportunities for Smart Systems

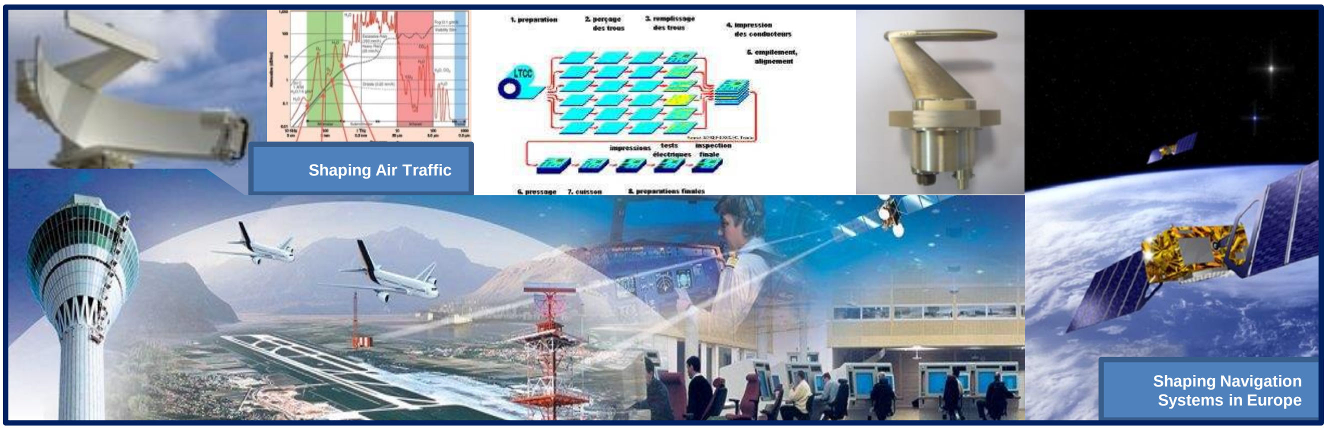
- Flight deck: More comprehensive information yet arranged so that the crew can remain focused.
- Multi sensor fusion and integration to gain a surer a more accurate representation of hazards.
- Conformal antenna and communications for passengers and aircraft data links for Ka band satellite access.

Hurdles to be overcome

- Monitoring of turbulence, a new requirement in Air Traffic Control (SESAR), and more accurate velocity measurements
- Security of data links and on-board connected electronic systems.
- Active and efficient antennas for high data rate in-flight connectivity .
- Reliability/safety/integrity of the communication of data.

Applications

- Remote sensing of weather to improve the quality of aviation.
- Increase air traffic capacity by reducing safe separation through Doppler monitoring of atmospheric air turbulences and wake-vortex turbulences with new generation radars
- Detection of wind shear in final approach (extreme cross-wind & headwind), allowing greater automatic landing and emergency landing capabilities.
- Better discrimination and plotting of volcanic dust emissions.
- Better trajectory prediction for the presence of UAVs in airspace shared with piloted aircraft.
- Better situational information for remote operators of UAVs.



Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

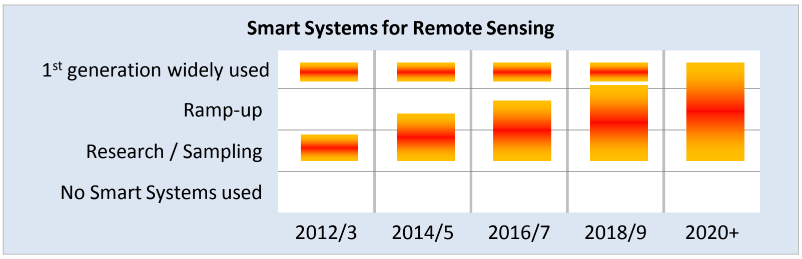
Sensor fusion and combination already exists in radar solutions. On-board Ka band active transceivers are foreseen for aircraft in flight.

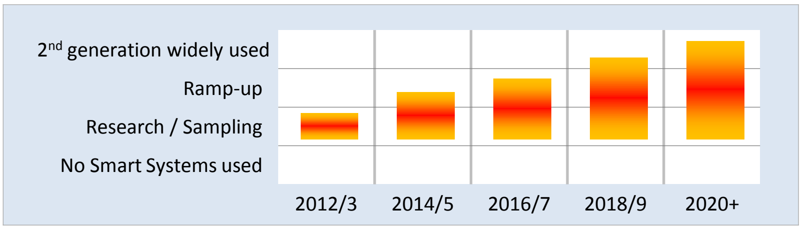
2nd generation Smart Systems are predictive and self-learning.

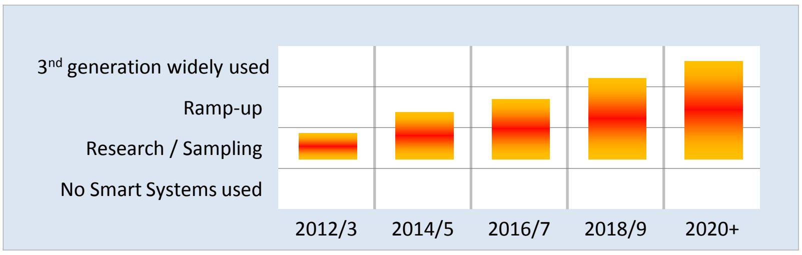
Smart Systems to combine control-flow / control data and event driven applications.

3rd generation Smart Systems simulate human perception/cognition.

Intelligent behaviour of systems according to the mission and predicted conditions.





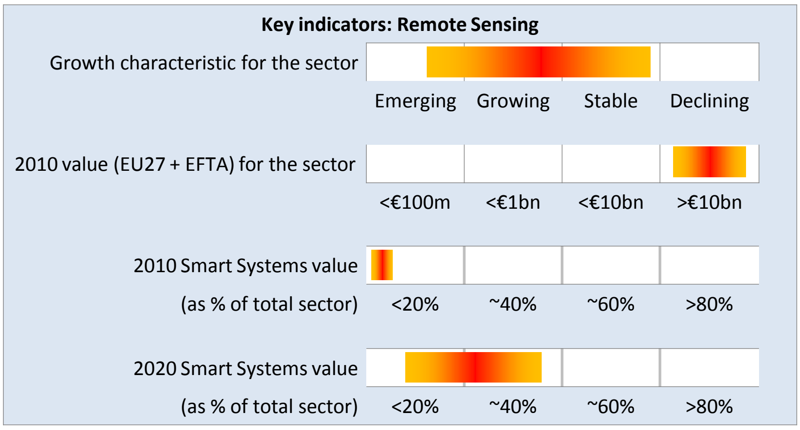


Sector forecast

Remote sensing of weather has been recognised as an important step to enhance the quality of aviation. Some classical and widely-used techniques are used (for example radar) and some emerging approaches such as THz and hyperspectral imaging are coming.

In-flight connectivity is demanded at low cost, which can be served by Ka band satellite communications by 2020 (reference IMS Research).

With more aircraft now offering Wi-Fi, passenger expectations are increasing rapidly. Despite the challenges and costs associated with providing Internet connectivity at 36,000ft and 500mph, passengers expect a similar service to that which they enjoy on the ground.



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Quick links:

Sector overview
Avionics & Control systems
Navigation & Guidance
Health & Usage Monitoring Systems
Remote sensing
EU Strengths & Research priorities

SMART SYSTEMS FOR THE ENVIRONMENT

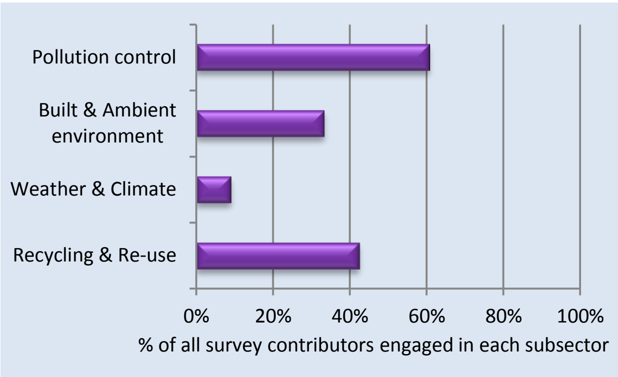
Smart Systems for the Environment

Overview

Smart Systems, with their ability to accept multiple inputs and to infer appropriate responses, are already finding application in local environmental conditioning controls.

Their ability to network, coupled with small size and low cost, is expected to enable area-wide detection and improvements not only in living and working environments, but also across the recycling and disposal landscape.

Gaseous CO_2 probe - *Vaisala*

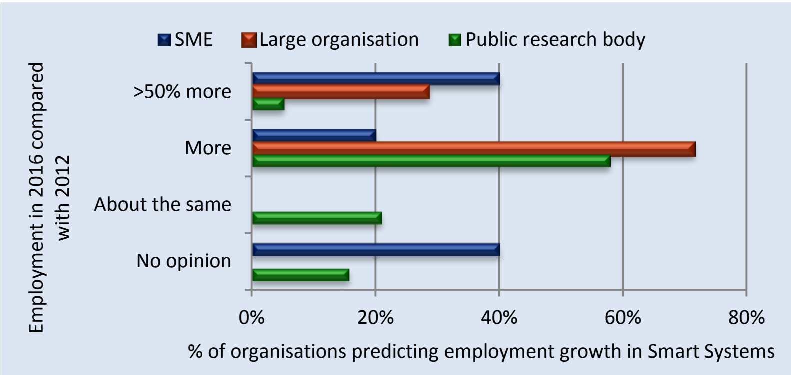


Profile of subsectors

In the IRISS 2012 survey, 33 Smart Systems providers, representing the supply chain from research through to market servers, revealed clear distinctions between subsectors (illustrated left).

Pollution control, and Recycling & Re-use have strong societal benefits in addition to their potential economic payback.

Technology impacts in Weather & Climate and the Built & Ambient environments will be accelerated by Smart Systems.



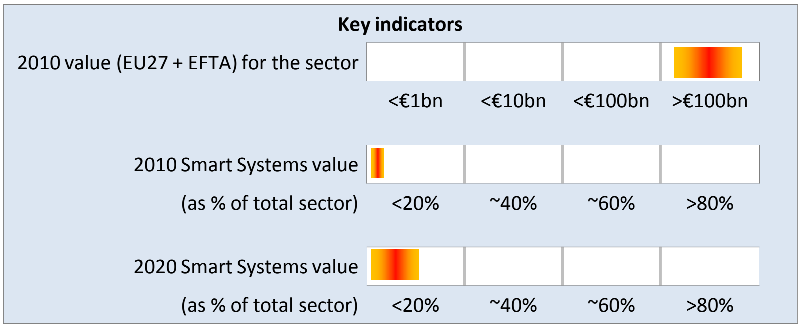
Growth prospects: Organisations

Of the Smart Systems providers surveyed, large companies and public research organisations forecast employment growth, with a significant proportion of SMEs predicting headcount increasing by more than 50% by 2016 but an equal number of SMEs expressing neutral opinions (illustrated left). There were no predictions of reductions in headcount.

Growth prospects: Whole sector

The total Environmental sector in EU27 + EFTA is immense in value (>€100bn). Currently Smart Systems account for possibly ~1-3% of this, but could rise to ~10% (>€10bn) by 2020 through the greater adoption of networked smart devices.

Tipping points may come from the availability of technology leading to mandatory use spurred by legislation and public concern.



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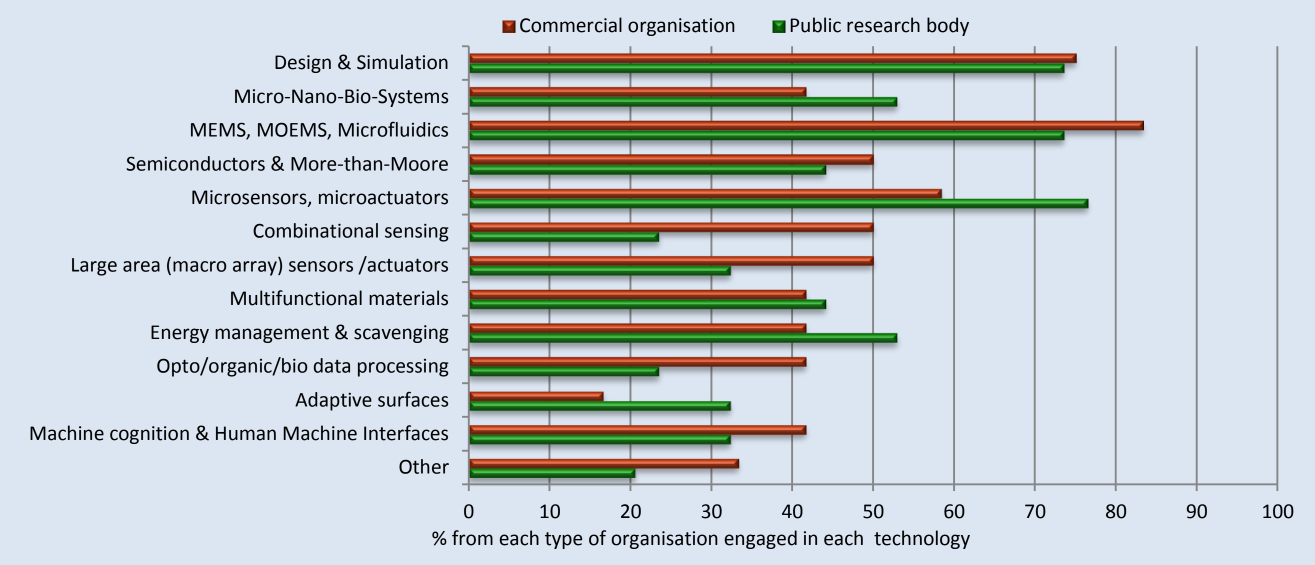
Underlying technologies



MEMS, MOEMS and Microfluidics, Design & Simulation, Microsensors & Microactuators, Semiconductors & More-than-Moore technologies, Micro-Nano-Bio-Systems (MNBS), Combinational sensing, and Large area sensors/actuators were the seven front-running technologies reported by companies engaged in the Environmental sector.

The environmental industry interest in Combinational sensing, and Large area sensors/actuators appears from the survey to outstrip the interest shown in these technologies by public research bodies.

Although the survey size, which included only 12 industry respondents, was rather small, a key issue for support action might be considered as:

- To sensitize public research bodies to industry needs for Combinational sensing and Large area sensors/actuators for application in the Environmental sector.

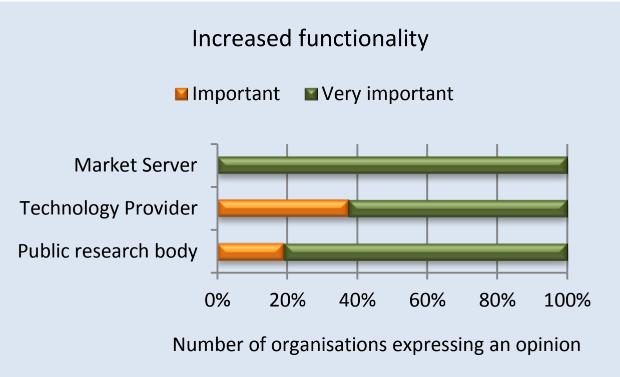
Drivers and barriers

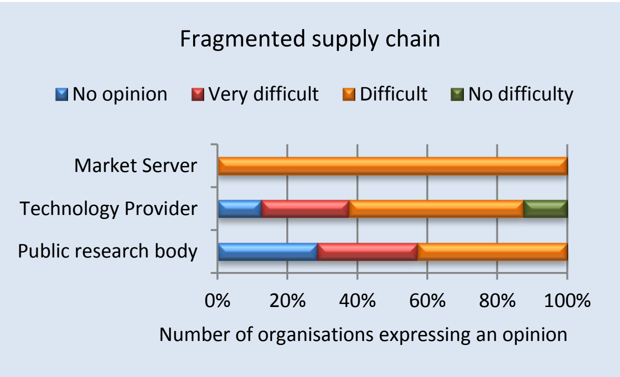
The survey of 33 Smart Systems providers to the Environmental sector rated "Increased Functionality" as the most important driver compared to, in descending order, Reduced Cost, Simplicity in Use, New Markets, Increased Reliability, Global Competitiveness, and legislative drives to compel the use of new devices or techniques.

The most obstructive difficulty reported was "Fragmented supply chain", responses indicating also that some 30% of public research bodies had no opinion about supply chain matters.

Accordingly, action should be considered to:

- Encourage researchers to gain better understanding of the Smart Systems supply chain to achieve a better match between research approaches and manufacturing capability





The sector in more detail

Environments – natural and built - surround us, they are the shells where we move, dwell and work. They impact us, and we impact them. Smart Systems can facilitate in this interaction. This may imply monitoring, control, remediation or adaptation. The agents and conditions involved differ depending on the actuation space. They may be classed as:

- open spaces (nature or urban),
- domestic confined spaces (buildings, offices, homes, cars, planes, etc) , and
- industrial environments (hazardous manufacturing sites, for example Chemical, Oil & Gas, Wastewater plants)

The matrices to be controlled are mostly air (outdoors & indoors), and water (fresh surface and ground water, pre-drinking water, water effluents & wastewater)

The parameters or species of environmental interest usually to be detected in those matrices are physical-chemical parameters, chemical and microbiological pollutants, gases and volatile organic compounds (VOCs), and radiation. The reasons behind these measurements range from improving our understanding (climate science), preventing danger or disaster (contamination, catastrophic climate events) or promoting comfort (ambient status).

More detailed examples of those parameters in the case of safety concerns are:

- Inorganic chemicals (anions: nitrite, bromide, fluoride, nitrate, chloride, heavy metals; pH).
- Organic chemicals (including drugs, pesticides, phenols, hydrocarbons, organic matter).
- Microbiological (for instance E. Coli, Legionella)
- Dangerous gases and VOCs.
- Electromagnetic waves and radiation.

Examples of parameters regarding the ambient:

- Temperature, humidity, light, CO_2, odours, noise..

The sector and its subsectors

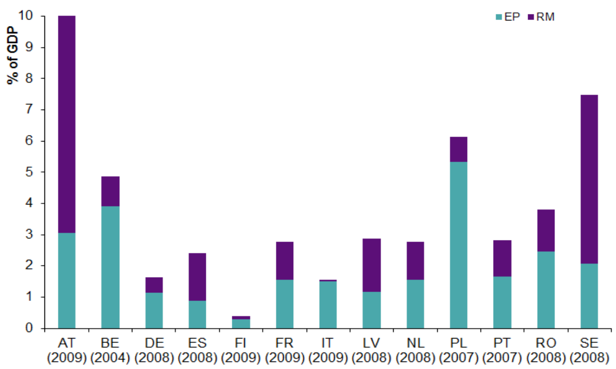
The Environmental Goods and Services Industry is defined by OECD/Eurostat as "The grouping of all producers of environmental products; these consist of cleaner technologies and products, pollution management services and resource management" [1]. Similar definitions are found in UK and US government documents [2, 3].

Here, the sector has been defined more broadly and divided into four main sub-sectors: Pollution control, Built & Ambient Environment, Weather & Climate and Recycling and Re-use. The first two are probably more amenable to the uptake of Smart Systems since they involve measurements for monitoring physical parameters and identifying chemical and biological species, with apparent synergies with the health, automotive and industrial control sectors, and initiatives such as Energy Efficient Buildings, Factories of the Future, and Smart Cities.

The Weather & Climate subsector is more related to distributed remote sensing and therefore faces specific challenges. It must compete/cooperate with existing alternatives like satellites. Whatever is achieved in this sector may however positively impact sectors like precision agriculture and transport safety.

Recycling & Re-use faces important challenges if one considers the large amounts of mixed materials to treat and the variety of materials to be identified, sometimes in minute quantities.

The environmental sector is legislation driven to an important extent, at least for long term changes where initiatives rely more often on governmental authorities. Market servers themselves are more important in the short term, in that they identify and determine the profit motive..



IT: Inlcudes non-market activities (waste, wastewater and water management only)
PL: Includes non market and ancillary activities
PT: Includes non market and ancillary activities

Benefits of Smart Systems

Smart Systems can mitigate our negative impact on the natural environment by better controlling emissions, they can alert and protect us from harm in hazardous situations, and they can make our life more comfortable in the built environment, the contained spaces where many of us spend most of our lives.

The relationship of Smart Systems with micro and nanotechnologies and with heterogeneous integration brings cost-effectiveness, ever-smaller form factors and ever-increased integration of functionalities (intelligence, connectivity, sampling, multi analysis, etc).

Different sector needs will require different solutions, but one basic advantage of Smart Systems is to go beyond the off-line mode of measurement of collecting samples and sending them to a lab, by providing ways of performing measurements and analysis in-situ, local or distributed, without delay, or continuously.

Smart Systems allow fast on-line measurements through portable approaches, in-line approaches and wireless sensor networks.

The portable instrument approach can be extended to disposable methods, sensor networks can be embedded in construction materials. In certain cases, a portable single instrument in an itinerant mode can be an alternative to a network of static sensors.

Itinerant instruments can be pocketable (for example within a phone) or installed (nodes in buses, cars, planes, UAVs). The collective response of many of these instruments can draw a dense map in time and space. Synergetic relationships with the Internet of Things can be envisaged.

Smartness is an added value to a measurement when it favours the self-learning capacity of the systems, allowing greater autonomy from users, faster reaction and the anticipation of situations.

Knowledge models are needed to make systems'' responses smarter, and for instance help to anticipate the spatial and time evolution of a hazard, for example a pollution cloud in a city, and to act accordingly, in a reactive or proactive way.

Photograph: *Frog Design*

Frog Design envisage smart face masks that protect but also sample pollution – communicating city-wide with other masks to provide a map of air quality

Technical Challenges

- Improved deployability of sensors (use flexible substrates, embed systems in structures).
- Remote sensing should be as autonomous and maintenance free as possible.
- Sensor response should be reliable and stable (drift-free or calibrated in-situ).
- Redundancy or multiple one-shot sensors are also an approach.
- Energy autonomy: power consumption of the sensors, peripherals and communication should be as low and possible, and energy sources beyond primary batteries are needed (e.g. renewable, harvesting, fuel cells with sample as fuel)
- Multianalyte capacity is another challenge. It may rely on an array of selective sensors for well defined problems, or on the chemometric response of non-selective sensors for less well defined situations; both approaches can be followed by chemical or optical (spectroscopic) sensors.
- Undefined situations like the gas emanations of landfills are the ultimate challenge in species identification, especially at low cost. The presence of expected gases can be checked for, but identifying a whole spectrum of unpredictable chemicals would require the miniaturisation of heavy duty lab equipment like mass spectrometers, unless there are breakthrough approaches.

European position

Europe is a strong advocate for stronger pollution legislation and stricter safety regulation at work, in public spaces and in the home. A culture of safety has been bred in Europe in the last decades, and there is a lot of environmental activism.

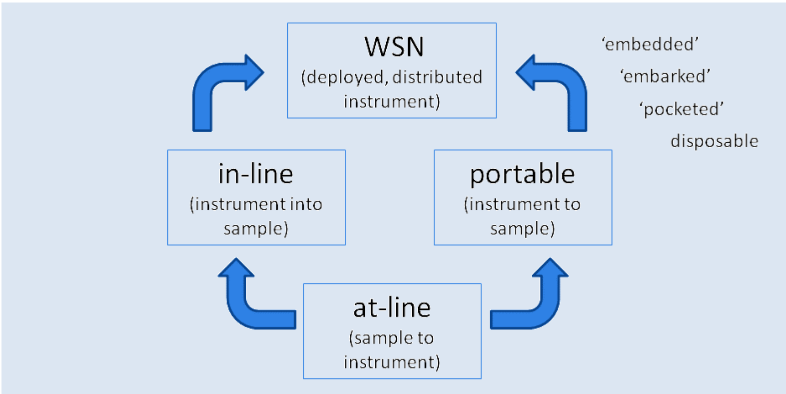
A similar growing public concern and regulatory effort is evident for recycling and re-use issues.

Environmental action in Europe began in 1970, and since 2006 there has been strong policy support for eco-innovation (namely, the Environmental Technologies Action Plan).

The breadth of involved techniques makes this sector an interesting one for research organisations, which have good positioning in physical, chemical, and biological sensing. However, practical implementation is weaker.

While almost 70% of the IRISS survey respondents from the research community claim an interest in environmental issues, the related percentage from private companies was less than 20%.

It seems that Smart Systems private producers perceive better business opportunities in other sectors that may resort to similar technologies such as Health and Safety & Security. The shift of private and public interest from clean-up measures and remediation to pollution prevention and optimisation of resources may open new markets.



Research overview

The goal of this sector is sustainability, by optimising behaviours and processes. Smart Systems can help remediate negative impact on the environment, but better still it can through improved monitoring and judgement of situations lead to less energy and resources consumption, and less waste and pollution.

In this sense, research should concentrate on advances in:

- Combinational sensing
- Multianalyte capacity
- Dealing with complex matrices with unknown constituents
- Sensor selectivity, long term stability and durability,
- System energy autonomy
- System procedural autonomy (automated sampling, maintenance free)
- Large area distributed sensing
- Increased levels of intelligence (information to knowledge to wisdom).

Pollutant emission control is a fairly mature field with legislation in collaboration with industry driving emission levels down as the result of a rapid take-up of technology.

Coordinating actions are strongly advised for all the other sub-sectors since the value chain is fragmented and the opportunities for applications immense.

References

[1] OECD definition Environment Industry; Eurostat document; http://stats.oecd.org/glossary/detail.asp?ID=6419;http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-RA-09-012/EN/KS-RA-09-012-EN.PDF

[2] UK government definitions of the Environmental Goods and Services Sector: http://www.bis.gov.uk/files/file35102.pdf

[3] US definition of Environmental Technologies Industry: http://web.ita.doc.gov/ete/eteinfo.nsf/068f3801d047f26e85256883006ffa54/4878b7e2fc08ac6d85256883006c452c

Smart Systems for the Environment: EU Strengths & Research priorities

Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Sector as a whole	•Strong legislation •Active public interests •Materials and processes knowledge •Strong research base •Important instrumentation companies	•So far the main customers are (money scarce) public administrations •Development costs •Deployment and maintenance cost	•ETAP stimuli •Cost affordable solutions may increase market and private interest	•Benefits from environmental action are often considered intangible
Pollution control	•Culture of safety •Good research in chemical and biosensing •World leading	•Authorities not very consistent, leading to unpredictable drives, and also differences between member states	•Extend applications for existing sensor technologies, eg microphone becomes gas detector, automotive radar become spectrometer	•Japan ahead in city-wide implementation
Built & Ambient environment	•Strong awareness of effects upon people •Visionary architecture aims to integrate intelligence	•Behavioural monitoring not yet recognised as a mainstream topic	•Implementation at the domestic level rather than public level	•Behavioural mediated monitoring held back by legislation/ planning in the EU
Weather & Climate	•Strong research base •Neuromorphic computing to solve complex predictive problems dynamically	•So far main customers are (money scarce) public administrations	•Smart System uptake following increased awareness of the costs of unexpected weather	
Recycling & Re-use	•Legislation •Public awareness	•Disobedience and organised crime	•Enhance urban mining, recovery of rare, valuable or useful materials •Systems that can assess the cost of retrieval against the value of materials recovered	•Without investment, potentially valuable waste is exported to other economies •Less regulated economies scavenge better

Sub-sector	Priority actions	Longer term actions
Sector as a whole	•Evaluate the tangible value of the application of Smart Systems to support already strong legislation and active public interest	
Pollution control	•Research to gain selectivity/sensitivity to pollution by combining a number of less selective/sensitive sensors •Separation and concentration of pollution samples to interface with smart devices •Non polluting deployable sensor systems	•Biomimicry based upon understanding natural processes to counter pollution
Built & Ambient environment	•Actions to collate the current status of the built and ambient environments, their opportunities for Smart Systems and the research needs	
Weather & Climate	•Actions to collate the current status of weather and climate forecasting, the value of the risks to be mitigated, opportunities for Smart Systems and the research needs	•Sensor networks for local agriculture •Networks for protection of wider infrastructure against flood/storm/fire
Recycling & Re-use	•Harmonised approaches by all member states regarding recycling & re-use •Actions to collate the current status, the rewards of waste management, opportunities for Smart Systems and the research needs	

Quick links:

Sector overview | Pollution control | Built & Ambient environment | Weather & Climate | Recycling & Re-use

Pollution control

Air Quality Monitoring Station – *John Evans, Wikimedia Commons*

Overview

Air, water and soil monitoring in open spaces and open hazardous installations (landfill, wastewater plants, industry).

Pollution control addresses a wide range of contaminants:

Chemicals inc gases & VOCs, organisms, solids – like asbestos and particulates - and radiation including also EMF, and acoustic noise.

Opportunities for Smart Systems

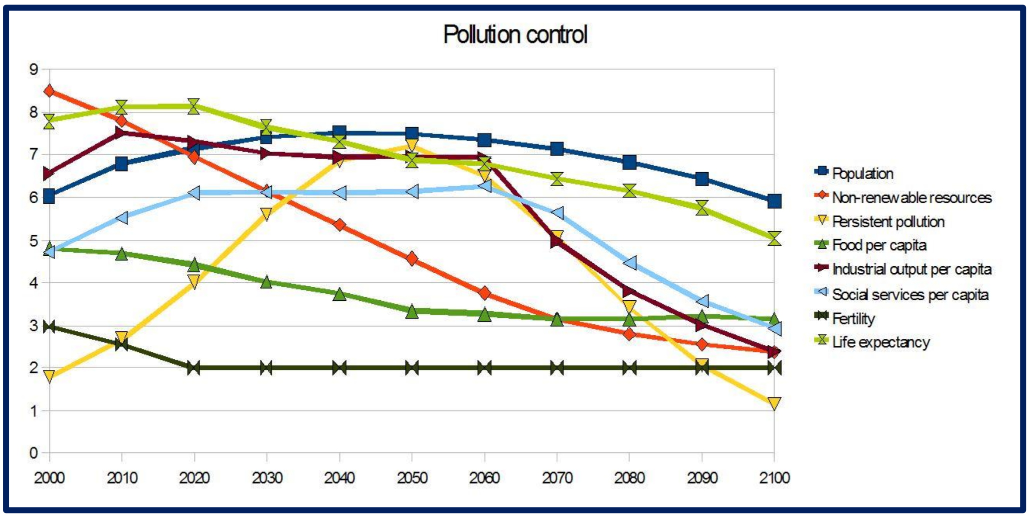
- Increased control enforced by legislation.
- Pollution control moving from alert to management.
- Remote sensing across large areas.
- Remote sensing in hard to access places.
- Closed control loops for reduced pollutant emissions at source.
- Deployment in itinerant personal platforms (For example, phones, cars, public transport).

Hurdles to be overcome

- Sensitivity issues (continuously decreasing detection limits)
- Screening of complex mixtures. Selectivity issues. Complex samples and complex interactions within the sample require adaptability and smartness
- Long term stability of sensors.
- Harvesting energy for large area networks
- Operation under harsh or dangerous conditions.
- Increasing number of potential pollutants
- Natural background levels of substances can differ and pollution alert must adapt to this.

Applications

- Hazardous industrial safety
- Emissions control and reduction at source
- Networked remote continuous urban air monitoring
- Networked remote continuous water monitoring (including emerging pollutants) and management
- Real time wide area surveillance systems for chemical, radiation incidents
- ‘Pocket’ spectrometer
- ‘Pocket’ e-nose or alternative biomimetic approach to detect a variety of pollutants with non-selective sensors



Source: World3 simulation

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

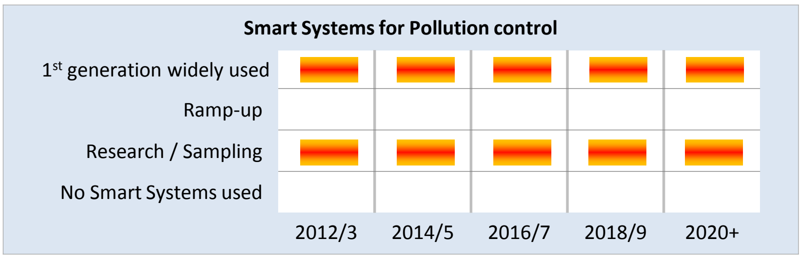
Current wide application of algorithms in automotive emissions, fuel injection and combustion. Further applications are being developed continuously.

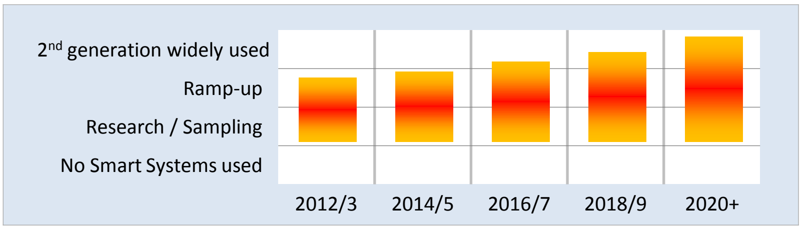
2nd generation Smart Systems are predictive and self-learning.

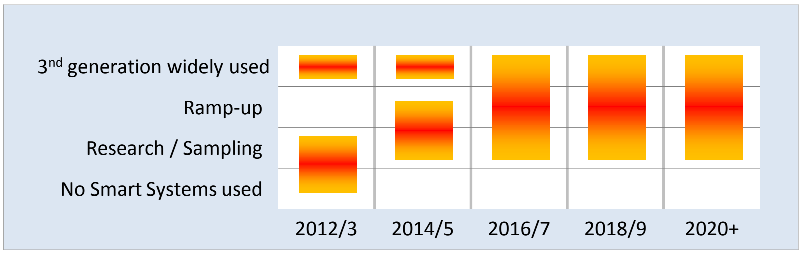
Self adaptive systems, systems that measure the potential for pollution from relatively simple measurements of conditions that can lead to pollution.

3rd generation Smart Systems simulate human perception/cognition.

Chemical databases, and knowledge of local conditions, can create an "expert" system. Already deployed in some small protected environments (for example, factories) but could migrate more widely through the Internet of Things.







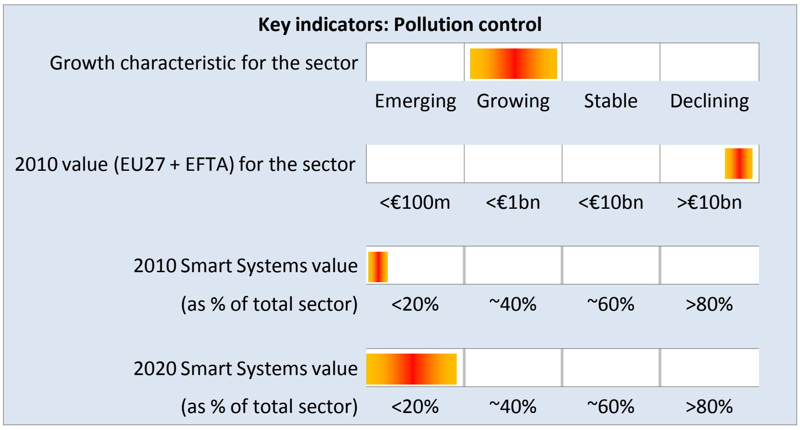
Sector forecast

A broader range of reliable sensing, and networking, will bring strong growth.

Interest in personal protection may bring smart pollution control technology to portable electronics gadgets, which may be also collaborate with extended autonomous monitoring networks.

Legislation will continue to accelerate the application of proven effective technologies, while political support initiatives such as the Environmental Technologies Action Plan, and the focus on eco-innovation in recent European research funding programmes will help new technologies to market.

The change of the pollution control paradigm from monitoring and mitigation to control and reduce will grow the need of smarter systems.



The indicators above are shaded to reflect uncertainty

Quick links:

Sector overview
Pollution control
Built & Ambient environment
Weather & Climate
Recycling & Re-use
EU Strengths & Research priorities

Built & Ambient environment

Overview

The built and ambient environments are not natural. They include the spaces where we live and operate, and could be in a car, or a theatre, for instance.

Human factors are important in keeping spaces safe, healthy, comfortable and functional. Temperature, humidity, CO, CO_2, ozone, VOCs, EMF, radon, legionella, moulds are examples of parameters of interest ranging from physical to chemical to biological, whilst psychological factors may include inducing calmness, readiness to act, or indeed readiness to flee in the case of an emergency.

Opportunities for Smart Systems

- Intelligent HVAC for energy efficient Buildings that sense and react to occupation and activity, measure pollution and monitor the health of occupants.
- Personal microclimate creation through smart textiles.
- Environment sensing in public and private spaces to monitor expected or unexpected personal behaviour, or crowd behaviour.

Sensor systems – *Siemens*

Hurdles to be overcome

- A wide range of parameters to monitor and control, leading to difficulties in integration in a single system.
- The environment is “invisible”, so costs need to be hidden too.
- Detecting behaviour, to help it or change it, depending upon circumstances (for example calm should change to urgency – but not panic – in the case of fire)
- Legislation protecting the individual against monitoring may slow the deployment of autonomous smart environmental control.

Applications

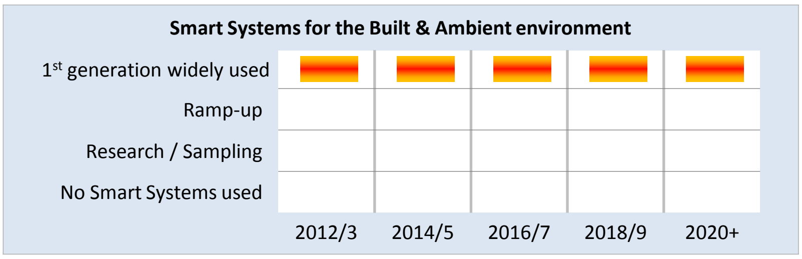
- Less energy, less water, less waste in the environmental management of contained spaces.
- Detection and remediation of aspects that may turn those contained spaces into unhealthy environments
- Detection of presence, age, genre, mood of individuals (by eye tracking, facial recognition, gait, etc)
- Environment reacting to the needs of the individual: Comfort - (temperature, humidity, CO_2, Oxygen)
- Operational safety in public spaces and transportation.
- Detection of individual or collective behavioural patterns that can lead to a dangerous situation.
- Physical extension of virtual social networks. http://www.bbc.co.uk/news/business-20965207

Introduction of three classes of Smart Systems

The three classes below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

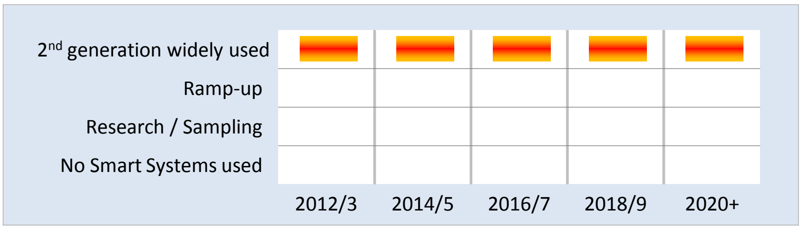
Ubiquitous controlled air environment in buildings, transit systems, cars. Even a simple thermostat is a primitive Smart System – it measures, then switches.



2nd generation Smart Systems are predictive and self-learning.

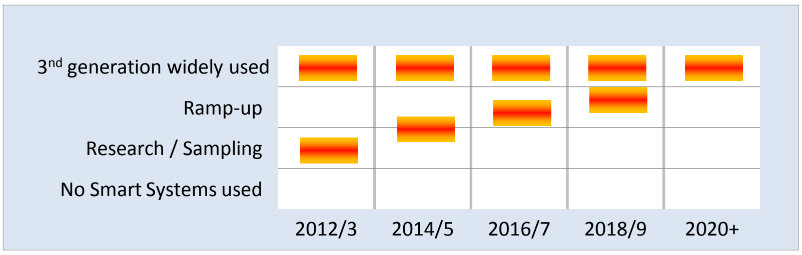
Predictive air conditioning could extend comfort and save energy.

Smart control of hot water distribution.



3rd generation Smart Systems simulate human perception/cognition.

Systems anticipating the needs of users and controlling accordingly their surroundings, for example smart entertainment, smart promotion of goods and services.

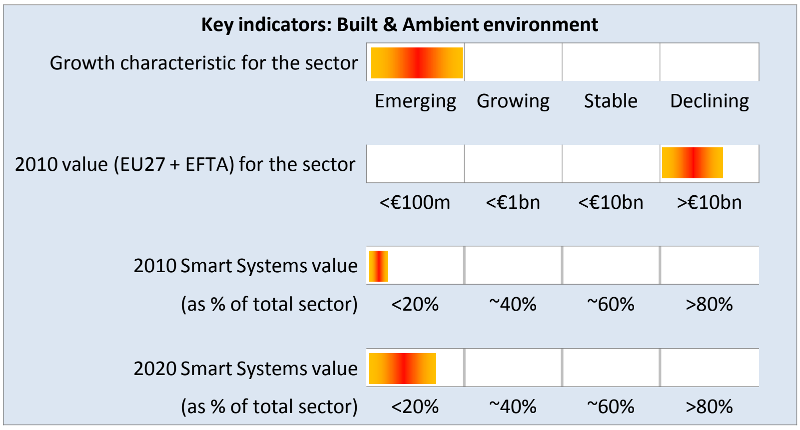


Sector forecast

By 2019 new office buildings must be zero emission in some countries, similarly for domestic dwellings. Smarter HVAC, adapted to occupancy and the immediate use of buildings will be needed to optimise energy budgets.

Work safety regulation will also demand better control of indoor conditions especially in less ventilated modern buildings. Growth is therefore expected. However, expectation is for very low cost implementation.

Behavioural mediated functional ambience with heavy ICT support may be an important added value in modern spaces. It is an emerging field in which the enabling potential of Smart Systems could be important. This field could be ethically controversial.



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Quick links:

Sector overview | Pollution control | Built & Ambient environment | Weather & Climate | Recycling & Re-use | EU Strengths & Research priorities

Weather & Climate

Overview

Weather and climate are fundamental drivers and limiters of human activity. Smart Systems can contribute monitoring for reducing the production of greenhouse and ozone depleting emissions, as well as providing detailed and predictive maps of weather/climate relevant parameters.

Opportunities for Smart Systems

- Forecast of anomalous waves in the ocean: compare with similar behaviour in non-linear optics.
- A network of wireless autonomous (freely moving) ocean sensors could monitor a number of parameters for weather, wave forecast and climate change.
- Optimise agriculture with real-time weather information by close to the ground information about the micro climate.
- Networking domestic (eg PV, i-phones) to make large scale weather sensors/predictors. Large scale and ultra-local.

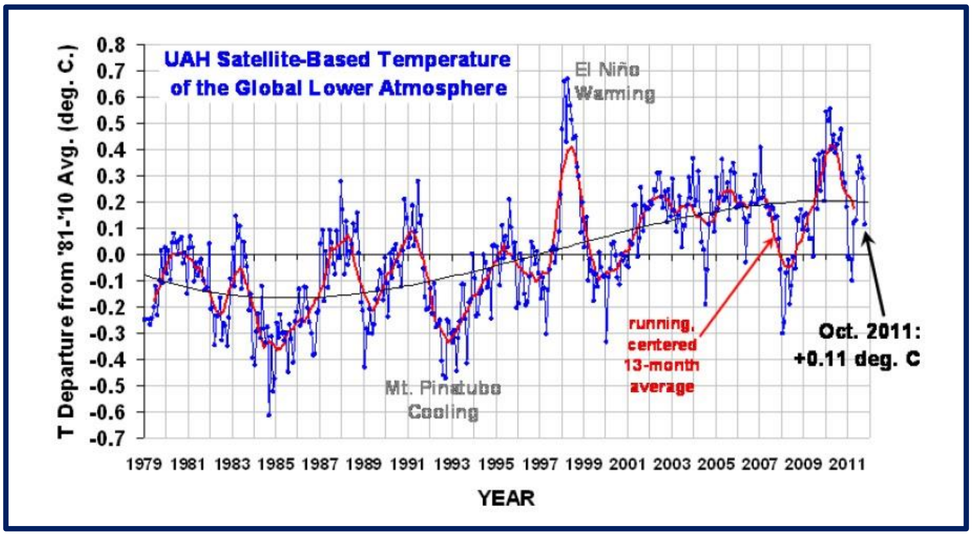
Weather Station – *United States Department of Agriculture*

Hurdles to be overcome

- Climate action by sensing at remote locations. (Combine climate sensing with oil exploration satellites, subsea robots).
- Packaging, energy supply, of sensors to withstand harsh conditions without servicing.
- Long term stability, built in calibration schemes.
- Large area networks. Connectivity issues.
- Energy autonomy of wireless sensor networks.
- Technology acceptance in developing societies.

Applications

- Distributed sensing of weather and climate relevant parameters.
- Precision agriculture. Optimum harvest time. Efficient use of irrigation resources in arid areas to create or maintain micro climates,
- Virtual sensors (coupling physical sensors with knowledge models) able to predict locally the likelihood of pest attacks. Optimum use of pesticides.
- System support for activities such as transport – air travel, tourism, insurance, etc
- Disruption and disaster prediction (flooding, hurricanes, snow slides, earthquakes or tsunamis, etc.)



Introduction of three classes of Smart Systems

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1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

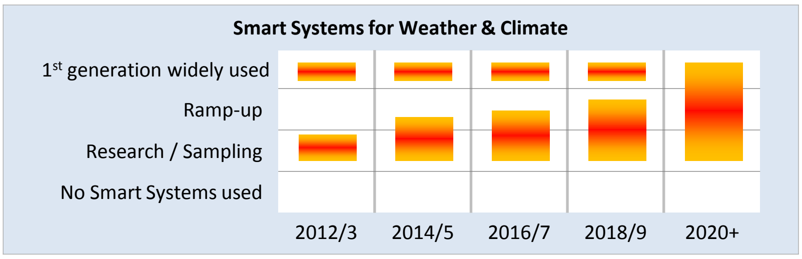
For example, automated weather stations, autonomous ubiquitous sensors for weather, climate and seismic surveillance.

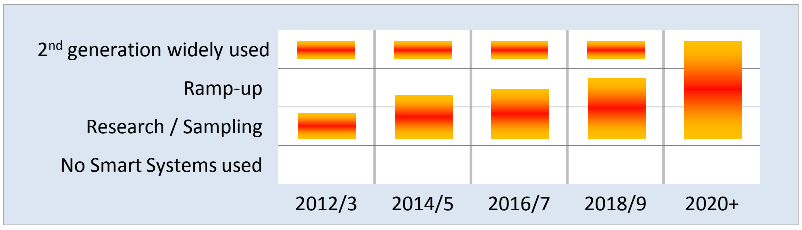
2nd generation Smart Systems are predictive and self-learning.

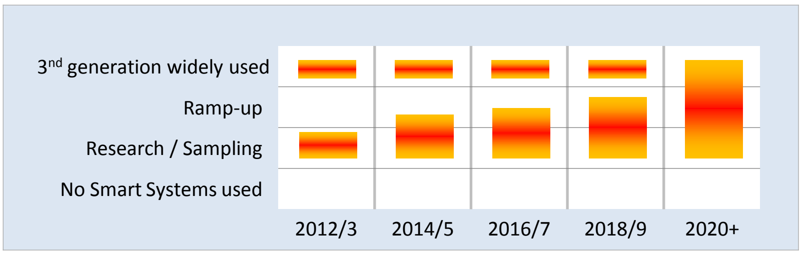
Feedback from weather or geophysical data to distributed stations can teach them to identify potentially hazardous patterns or situations.

3rd generation Smart Systems simulate human perception/cognition.

Advanced weather pattern recognition based upon the abilities of experienced forecasters.





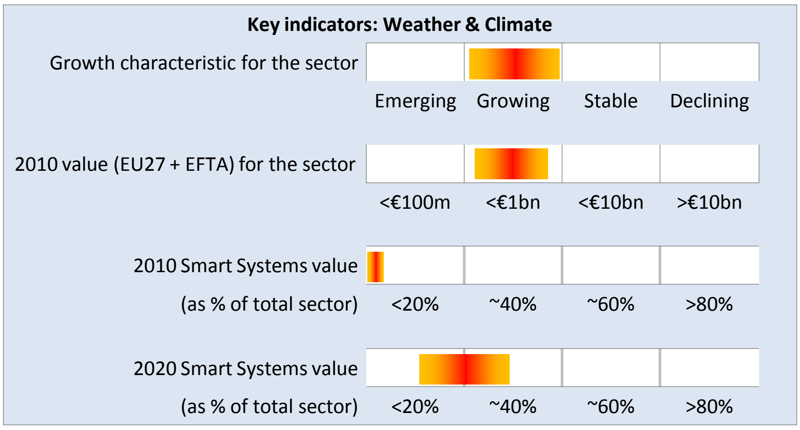


Sector forecast

A very large growth opportunity for Smart Systems should arise since a significant percentage of activity in this domain is related to monitoring, The Smart Systems contribution may be much greater than in other environmental sectors, once the real monetary value of accurate weather prediction is proved.

Smart Systems installed in transport, aerospace, energy and environmental applications will provide valuable weather and climate data to improve the understanding and modelling of medium and long-term climate evolution.

With more extreme weather patterns emerging with global warming, the need for more accurate mitigation and warning will stimulate growth in the sector.



The indicators above are shaded to reflect uncertainty

Quick links:

Sector overview | Pollution control | Built & Ambient environment | Weather & Climate | Recycling & Re-use | EU Strengths & Research priorities

Recycling & Re-use

Overview

This is a most favoured form of preventive waste management with positive impacts upon environmental protection and the conservation of natural resources. It sits on the top of the waste hierarchy:

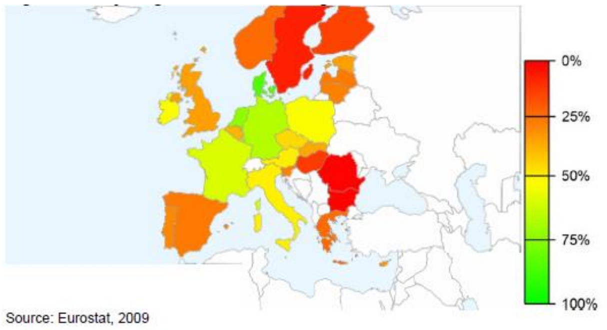
- Extended life by upgrade, or a second life for a new purpose.
- Possibility to disassemble and reuse components.
- Recycling of materials (with possibly higher recovery rate after separate collection and disassembly.
- Incineration with energy recovery
- Landfill

Recycling and Re-use would benefit from Europe-wide laws enforcing and harmonising their implementation.

Opportunities for Smart Systems

- Give new properties to materials and systems to make them more reusable, identify themselves.
- A smart system could "assess" a discarded item for its useful parts or functions and enable more effective urban mining.
- For recyclers, fast assessment of valuable and/or hazardous materials and more effective urban mining in general.

Recycling rate of total waste 2007
(ETC/SCP working paper 5/2010)



Source: Eurostat, 2009

Hurdles to be overcome

- Discriminate materials in automatic mixed garbage sorting.
- Find business models to enhance reuse of product and components,
- Provide systems to eliminate the market in counterfeit electronics and high technology / safety critical components.
- Design for disassembly.

Applications

- Equipment aimed at controlling and measuring the generation and storage of waste, its toxicity, etc will allow for more efficient removal of hazardous materials from the waste stream.
- Equipment to help in waste separation, sorting recoverable materials from waste streams, sorting of mixed garbage, for example when mining in closed landfills, will allow for more efficient recovery of precious metals.
- Smart products may reconfigure as the user requires new functions, rather than being thrown away and replaced. An example would be a computer that is be upgraded rather than replaced.
- "Canaries" built into in products, enable assessment of useful second and third life of a product. Or reuse of components.
- RFID in product to simplify reuse, recycling, for recyclers (eg SMART TRASH: Study on RFID tags and the recycling industry, Interim Report (D3) SMART 2010/0042)

Introduction of three classes of Smart Systems

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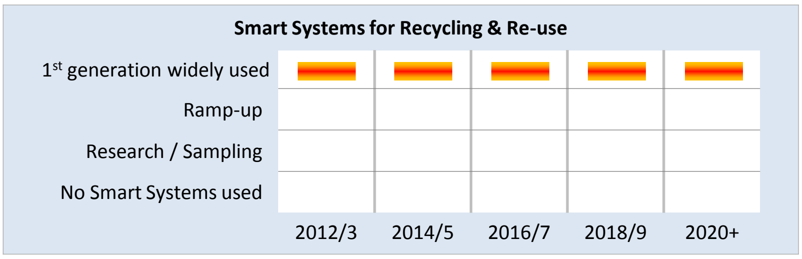
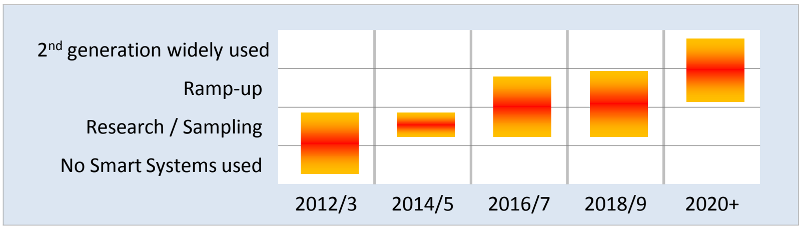
Machine sorting of waste, for example fast in line identification of steel quality by laser induced breakdown spectroscopy (LIBS)



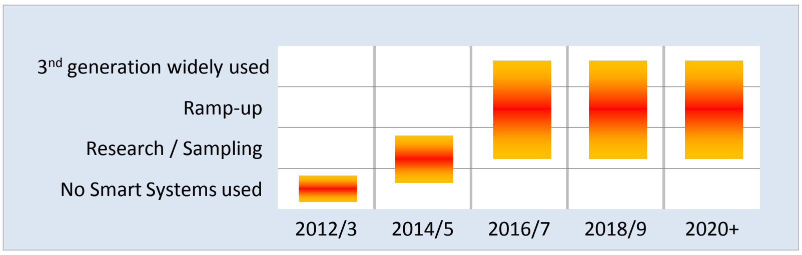
2nd generation Smart Systems are predictive and self-learning.

Assessment of non-homogeneous materials for re-use.



3rd generation Smart Systems simulate human perception/cognition.

Gadget or equipment predicts its life, suggests its replacement and suggests its second use.

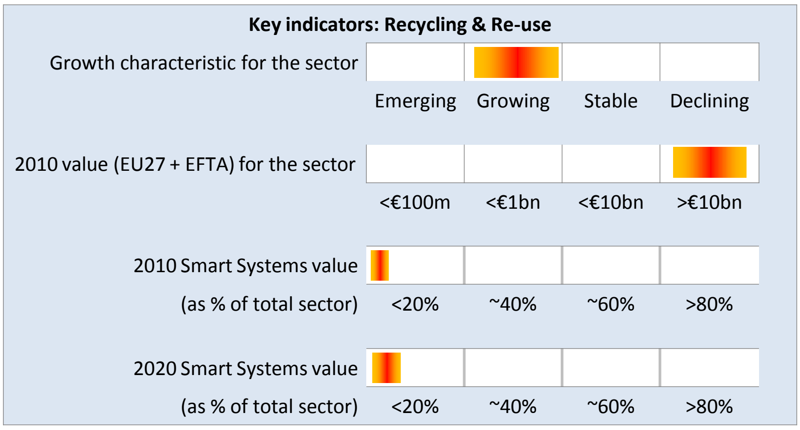


Sector forecast

The increased demand of materials for products and infrastructure globally will increase the demand for recycled materials.

Furthermore, many high technology products depend upon scarce materials such as rare earths. This will spur the case for re-use. Business cases will have to be carefully constructed to enable sustainability and growth of this part of the sector.

Legislation may have an impact, especially for cases where hazardous materials are substituted for less hazardous ones. But this also affects materials recovery of historic materials since hazardous parts of a product must be taken care of in order to remove them from the recycling stream – smart systems could record and deploy legacy experience..



The indicators above are shaded to reflect uncertainty

Quick links:

Sector overview | Pollution control | Built & Ambient environment | Weather & Climate | Recycling & Re-use | EU Strengths & Research priorities

SMART SYSTEMS: SAFETY, SECURITY & RELIABILITY

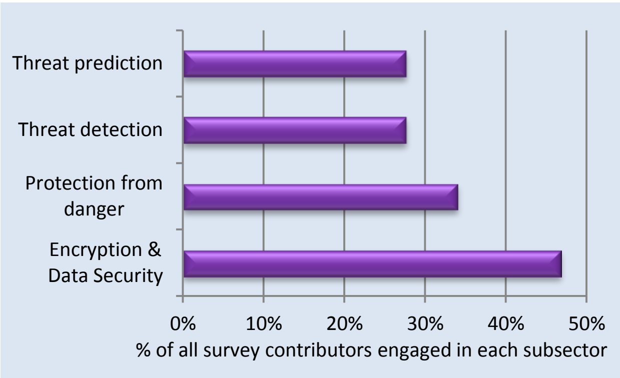
Smart Systems: Safety, Security & Reliability

Overview

Smart Systems, with their ability to make autonomous decisions based upon a combination of events – perhaps sensed in multiple domains – promise to be strong enablers to safeguard life, property and information.

Safety, Security and Reliability are transversal across all market sectors. Applications cover a full range from the protection of transactions and identity through to the continuous monitoring of food quality.

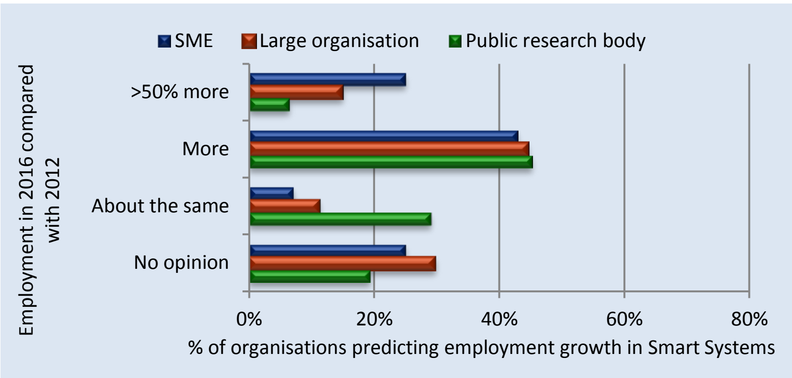
Near Field Communication – *Gemalto and NXP*



Profile of subsectors

In the IRISS 2012 survey 47 Smart Systems providers, representing the supply chain from research through to market servers, revealed distinctions between subsectors (illustrated left), but further analysis showed that those involved in “threat prediction” are the same organisations that are engaged in “threat detection”.

Encryption & Data Security emerged as the most prevalent activity, indicative of the focus required by an increasingly connected and automated world.



Growth prospects: Organisations

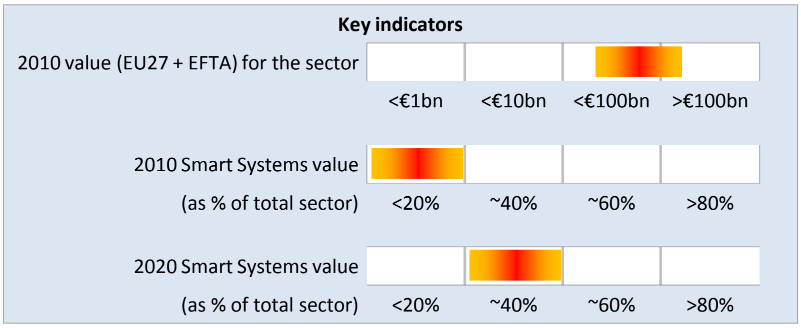
Of the Smart Systems providers surveyed, the great majority forecast employment growth, with a significant proportion of SMEs predicting headcount increasing by more than 50% by 2016 (illustrated left). There were no predictions of reductions in headcount

A similar picture emerged for growth in financial terms.

Growth prospects: Whole sector

The word wide and European Safety & Security sector is very broad. Safety and security electronic equipment accounted for €141bn revenue in 2011.

Currently Smart Systems account for possibly ~20% of this, but could rise to ~40% (>€80bn) by 2020 as cities scale, as transactions scale, as part of electronics in mobile transport, and as part of the growth in health services.



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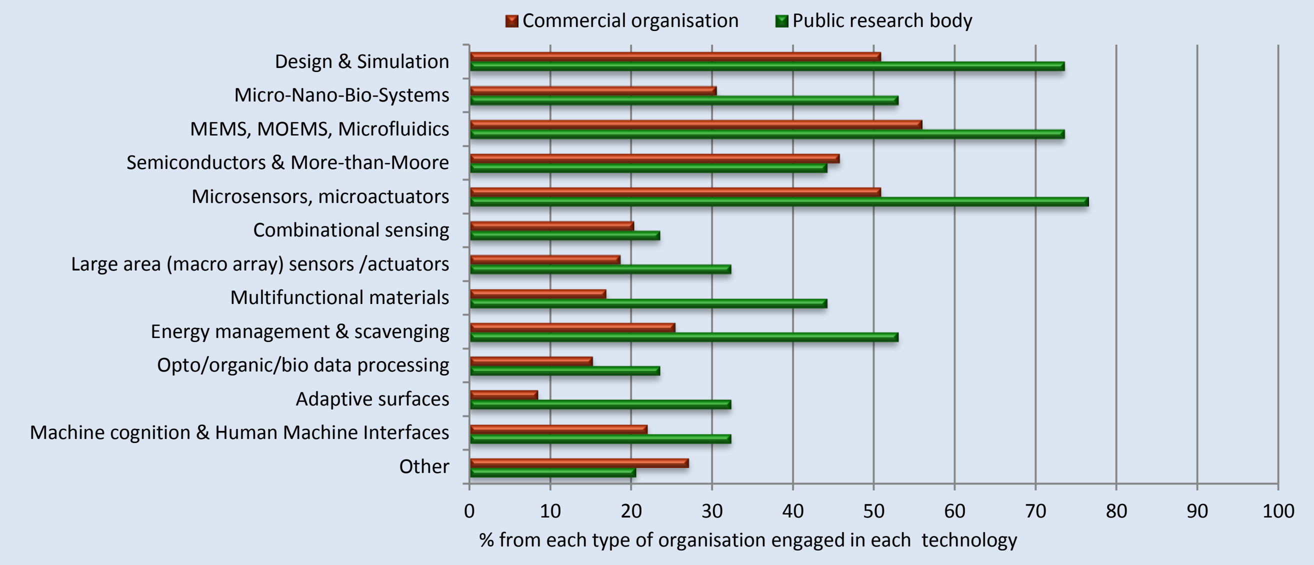
Underlying technologies



The four front-running technologies reported by Safety & Security companies were respectively: Microsensors & Microactuators, MEMS, Semiconductors & More-than-Moore technologies, and Design & Simulation.

A key issue for support action in Safety & Security should be:

- Implementing trustworthy manufacturing process while developing 'design for manufacturing', 'design for testing', and 'design for reliability' with diversity of materials combined with increased system complexity.

A high proportion of Public research bodies report undertakings in Energy management & Scavenging, which seems to have penetrated rather less into commercial application than might be expected, considering the potential advantages of the technology for powering autonomous "sentry" devices. A further action should therefore be:

- Strengthening the exploitation of Energy Management & Scavenging technologies

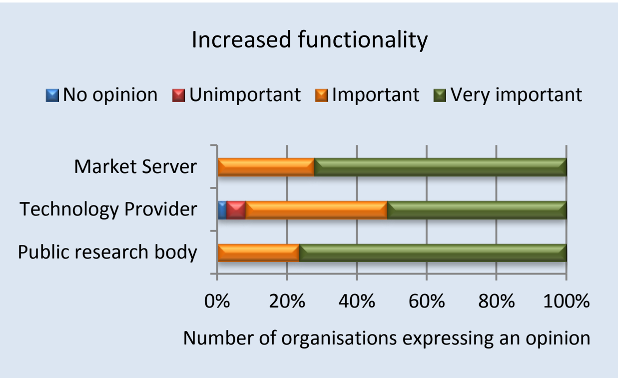
Drivers and barriers

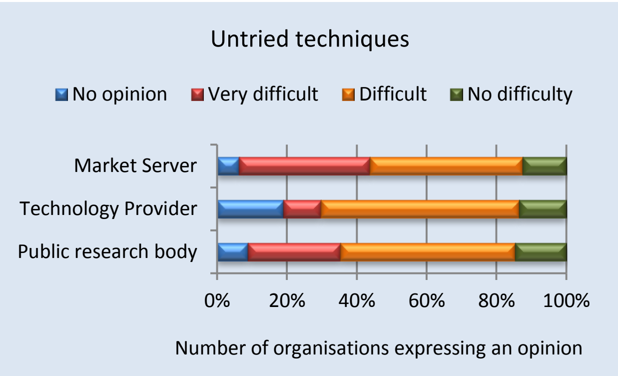
The survey of 47 Smart Systems providers to the Safety & Security sector rated "Increased Functionality" as the most important driver compared to, in descending order, Increased Reliability 37, Reduced Cost, Global Competitiveness , New Markets , Simplicity in Use, and legislative drives to compel the use of new devices or techniques.

The most obstructive difficulty reported was "Untried Techniques". This is instructive as the Increased Functionality Driver is most likely to be satisfied by Untried Techniques.

Accordingly, action should be considered to mitigate the risks entailed in the uptake of Smart Systems by:

- Recognising safety, security and reliability as significant enablers of future European Nano-electronics, Embedded and Smart Systems.
- Defining protection profiles for future applications to make them secure and safe.
- Bringing the full chain suppliers and SME in actions
- Encouraging tighter inter-disciplinary R&D



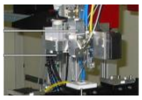


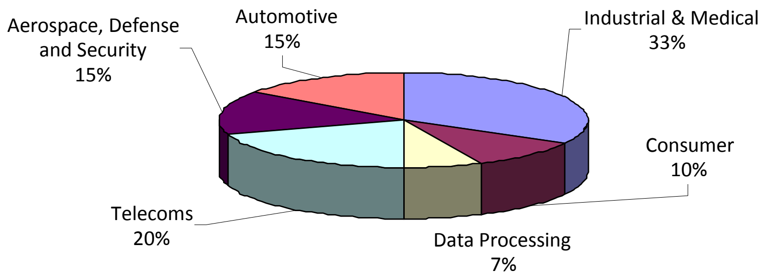
The sector in relation to other sectors

Europe has now specialized in critical systems, where the most important property is the dependability of the system. It reflects the user's degree of trust in that system. Safety and security is transversal across all European sectors, and as such brings:

- Safety in aerospace, automotive, industrial and health; to operate without accident or catastrophic failure.
- Security in banking and payment, city and rural infrastructures, communication networks, and now also in the internet, cloud, health, smart grid, and many more interconnected systems; allowing them to operate despite accident or intrusion, and to preserve privacy and the security of individual items.
- Reliability in every application that requires the delivery of specified services.
- Maintaining the availability of emergency services, telecom, energy and water/waste networks; ensuring their ability to deliver services when requested

Benefits of Smart Systems

		Example of Safety or Security	New feature from Smart Systems
Aerospace		Keep low airplanes accidents Navigation and guidance Security controls at airport Operation of UAVs in normal airspace	Wing surface monitoring in airplanes Smart System checks for contaminants, and also explosives and narcotics
Communications		SiM card ePayment, e-Banking; Integrity of controls, routing and billing ID	Secure and safe deployment of IoT. Biometric identity checking of doctor and patient and for access control. Near-field communications
Energy		Smart metering in Smart Grid SCADA/industrial control systems Protection of sensitive sites and of distribution	Green home appliance control Fail-safe robotics, globally connected to sources of knowledge and experience
Environment		Fire detection, intrusion detection, access control, Crowd behaviour in public spaces Smart cities	Recognise anomalies, change environment to instil calm, or urgency
Health & Beyond		Treat personal health data in privacy Telemedicine Security of dangerous drugs in body-worn devices	Patient monitoring at home, with continuous surveillance of health, proximity of the patient and unusual activity
Manufacturing		Physical safety of human co-workers Robotic co-working But also Design for reliability Avoid copying products	Automated inspection processes for the manufacturing of reliable products Vigilance of surroundings and behavior of co-workers
Transport & Mobility		Driver assistance navigation and in the future driverless vehicles Radar for cruise-control and parking In-vehicle data security	Smart sensors and systems for driveway management Smart e-actuators for e-mobility V2x communications



Europe produces 20% of WW 1400B€ Electronic Equipments : above chart provides the distribution per sector in Europe. ref European Nanoelectronics Forum 2012, Munich, Cabinet Decisions

Application sectors	European share of worldwide production
Industrial & Medical	23%
Aerospace & Security	23%
Automotive Electronics	21%
Telecoms Equipment	10%

Safety, security and reliability across the sectors

Air transport

Photograph : *United States Coast Guard*

Autonomous drones – gaining wide access to US airspace by 2015, and 30,000 flying worldwide by 2020 – will be a huge driver for light, efficient, Smart Systems development

As stated in the Advisory Council for Aeronautics Research in Europe (ACARE) Strategic Research and Innovation Agenda,, the progress of aviation safety since the 1960s has been impressive. Lessons have been learnt from the accidents of the past and effective mitigations have been implemented to reduce the probability of similar events today and in the future. This naturally results in the identification of new causes that were previously masked.

The safety goals beyond 2020 are very ambitious when compared to the current commercial operations:

- Reduce the number of accidents.
- Mitigate the effects of weather and other hazards.
- Operate in new airspace shared with unmanned vehicles.
- Provide easy and secure passenger boarding and travelling,.
- Make all aspects of air transport resistant to cyber-attacks.

To achieve these goals, the sector requires 3rd generation Smart Systems devices, from a well-qualified and highly traceable European supply chain.

Communications

Smart systems are key enablers to improve the quality of life for citizens through energy efficient ubiquitous interoperability and secure access to services

Network security, availability and reliability are now essential for the functioning of our societies and economies. Major application sectors making use of Smart Systems, such as Energy, Health, Communications, Transport and Finance, have potential vulnerabilities that must be mitigated using trustworthy ICT systems and solutions.

Examples include industrial control systems, payment transactions using mobile phones/e-cash, the integrity and availability of patient medical data in telemedicine, the security of intelligent implanted medical devices, and safety critical software for vehicle-to-vehicle communications.

As stated in Networked Society (NetSoC) Strategic Research and Innovation Agenda for the 3 ETPs: Net!Works, ISI, and NEM, the most important requirement National Critical Infrastructures (food, water, transportation, electricity) is high availability and robustness, much higher than that normally required in communication network designs of usually 99.9%.

Authentication of mobiles inside enterprise networks but also everywhere in mobility is already a challenge. Payment applications demand even more security attention. With the cloud, businesses are implementing new ways to store, deliver and move data throughout the network, and need protection.

Smart Systems research needs to link to advances being developed in the IT security industry and academia, e.g. in multi-modal authentication (combining different techniques to increase confidence), and strengthened reliability and resilience through the design and manufacture of fault-tolerant systems.

Safety, security and reliability across the sectors

Energy

The distributed nature of renewables presents additional challenges for seamless integration into the existing grid structure

With climate change and the need to conserve fossil fuels, the energy world is changing. One energy focus for Smart Systems is electricity, and its generation and distribution and use. Related concepts may also apply to other utilities.

The smart grid will have numerous components. One is an Advanced Metering Infrastructure (AMI) which includes smart meters. In addition to the tariff, billing and taxation related roles of smart meters, these energy management units will be able to control distributed generation (like photovoltaic arrays), energy storage, demand-response, and the local electricity resale market, which will extend to the charging of electrical vehicles.

The challenges in the smart energy area include fraud prevention, privacy protection (as smart-meters may allow the extraction of very specific information about consumers' private lives) and critical infrastructure protection (shutting down the electricity in an area viewed as dangerous or threatening by the emergency and security services).

Suitable technologies and service development platforms are needed to bring trust in the smart energy ecosystem and to secure it.

The built environment

NiCE – Networking intelligent Cities for Energy Efficiency - is an FP7 funded project which supports cities in the achievement of their goals as outlined by the Green Digital Charter: www.greendigitalcharter.eu/niceproject

By 2050, 70% of the population will live in cities according to United Nations Department of Economics and Social affairs. Cities, some of which are already on the edge of infrastructure failure, will face increasing demands for a safe and secure environment.

Analyzing the outcomes of the first experimental smart conurbations have identified key security challenges.

One of the challenges is to create new tools and methods able to provide a high level of security and privacy for smart cities against cyber-attacks, and how to deploy them in a timely manner.

These security features will need to incorporate techniques for Authentication and access control, intrusion detection (including weak-signal mining and processing), robust and secure system design, secure communication capability with strong resilience capabilities, whilst avoiding avoiding false alarms and prioritizing alerts.

The question is how to create adaptive security solutions that can be used to secure Smart Systems which have a degree of autonomy and the capability to control not only comfort and convenience, but also life-sustaining systems.

The distribution of intelligence into networked Smart Systems, and their individual and collective ability to corroborate information gained through multi-parameter sensing is a promising approach.

Safety, security and reliability across the sectors

Medical devices

New generations of defibrillator will rely on Smart Systems technology - Sorin

Medical devices are expected to keep privacy and integrity of the patient data and to avoid non-authorized access. Hacking of implanted medical devices has already been reported.

It is becoming usual for medical devices to have strong data encryption, but the problem remains of how to handle the private or public keys and keep them secret while allowing simplified access in emergency situation. Hardware circuits like those used in secured microcontrollers promise the best protection.

A smart System approach will see a low footprint and low power consumption allowing real time data transmission from body worn or implanted sensors. Smartness could provide the right balance between security, high reliability and usability.

Manufacturing

rapyuta.org – Bart Van Overbeeke Fotografie

Safety is one of the key factors in manufacturing, primarily to protect workers and the public at large, but also to ensuring that production is efficient and free from disruption.

In process control, reliable systems guard system stability, enforce safe limits to reduce the probability of accidents and provide predictability of control system behaviour.

In factory automation, the threat of copying and hacking requires anti-cloning and secure mechanisms.

Smart Systems, with their multi-sensing and predictive abilities, promise the physical safety of human workers, and safe interactions with of robotic co-workers – that in turn need to respond appropriately to a great variety of behaviour in their human partners.

Transport & Mobility

Smart Systems offer optimisation of vehicle control, navigation and logistics potentially across multiple modes of transportation

Due to the increasing introduction of safety-related applications as reported in the Transport & Mobility chapter, Smart Systems in this critical area need to be extremely reliable, and to provide graceful degradation mechanisms in case of fault.

Furthermore “data security” within the in-vehicle network has become a serious topic, to counter “cyber attack”, engine tuning, unwanted billing for road use, EV charging and insurance. Several solutions have been proposed by means of multi-core processors and hardware mechanisms for secure access to/from internal memory/resources.

The demand for mobility is still increasing, but car use has been reducing in many countries. Demand is shifting to mobility as a service where users can benefit from seamless multimodal transportation.

For mass transport, seamless authentication and payment systems need to match the Smart System approach to journey planning and execution. That is evolving very quickly.

Introduction of Smart Systems

European industry leaders providing secure and safe electronic equipments are facing new challenges:

- New societal challenges are demanding massive smartness and connectivity while preserving reliability, safety and security.
- More and more Smart Systems will be created combining sensing, data processing, decision making and actuating (or controlling) functionalities using new materials and packaging, bringing greater challenges for reliability than those encountered in standard microelectronic components.
- New IT attacks are occurring every day, now threatening the objects and personal items which have become always connected.

The three classes of Smart Systems below do not necessarily succeed each other in time: the nomenclature "generation" indicates increasing levels of "smartness" and autonomy.

1st generation Smart Systems include sensing and/or actuation as well as signal processing to enable actions.

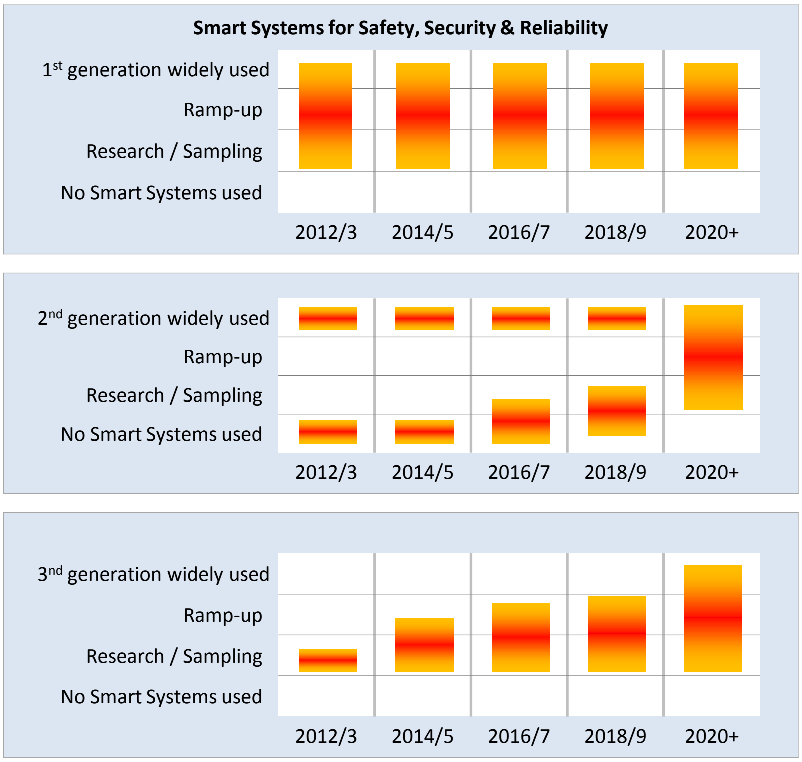
Air bag sensors, gyroscopes in aircraft, and area protection with passive infrared, microwave and sound sensors are common, but more are developing.

2nd generation Smart Systems are predictive and self-learning.

Secure smart cards, identity, access control, and cash products already exist. But for safety, major challenges are to deal with tolerances and aging of new key components.

3rd generation Smart Systems simulate human perception/cognition.

Truly cognitive Smart Systems, with multi-sensing and predictive abilities, are needed to guarantee the physical safety of human workers in the presence of robotic co-workers.



Research overview

A combined approach must be developed to ensure safety and security in Smart Systems:

- Define protection profiles for the new applications enabled by Smart Systems.
- Identify and transfer existing technologies and safety/security compliant techniques into domains changed by Smart Systems. For example, manufacturing processes need to learn from aerospace.

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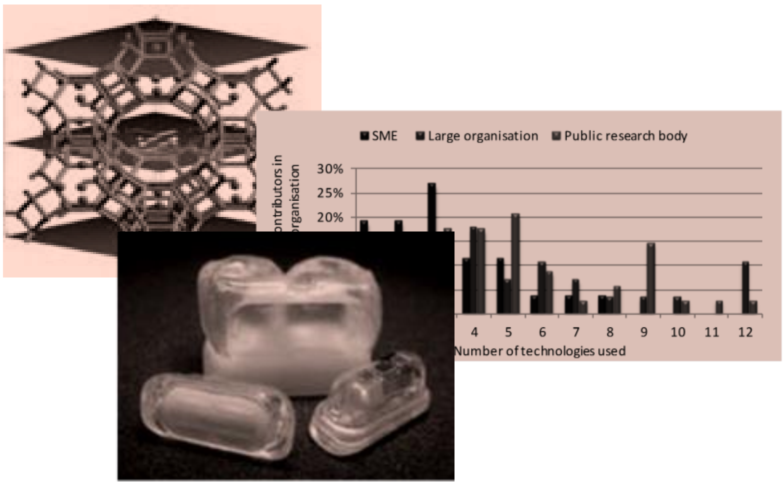
Safety, Security and Reliability: EU Strengths & Research priorities

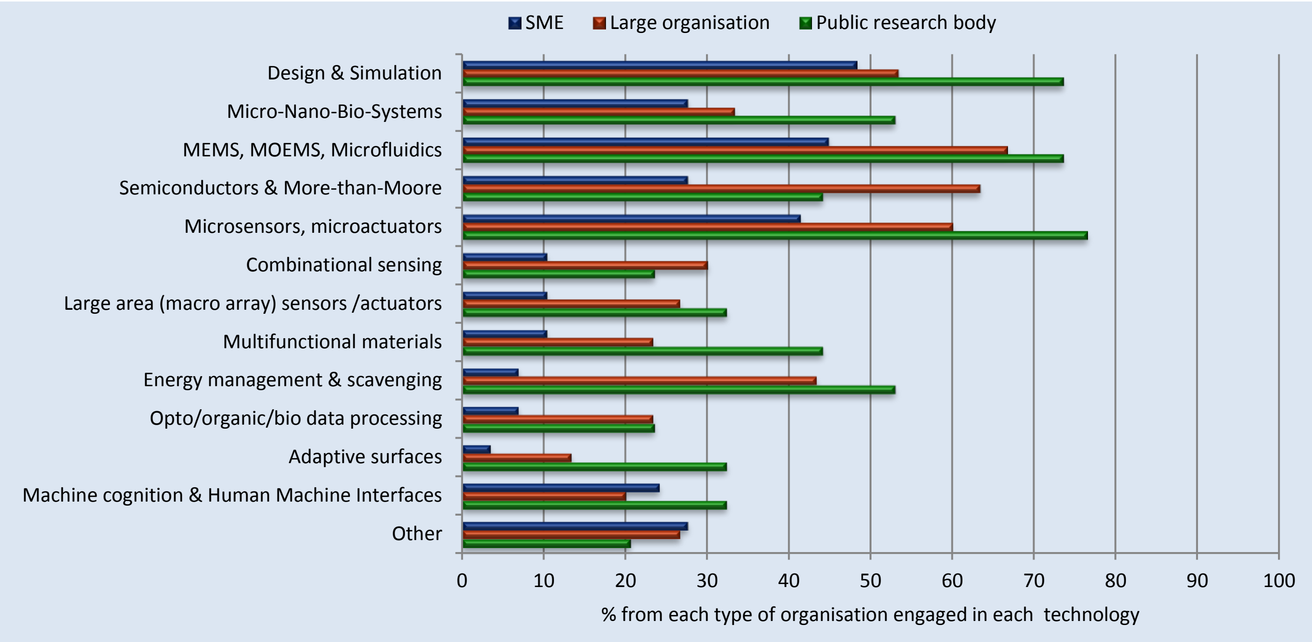
Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Sector as a whole	• Europe lead & expertise re security & safety-critical systems • Leading European companies; Legislation-led • Safety conscious culture	• Difficult for SME to access all standards	• Capitalize on European expertise, set the bar higher, differentiate and take the lead regarding secure & trustworthy implementation for European embedded applications	• Denial of services for new applications when not secured • Counterfeiting • European accredited supply chain for Smart Systems may become weak
Threat prediction and detection	• Manufacture of products that contain safety or security aspects remains in the EU, and command higher value	• Application denial of services	• New security models • Migrate knowledge to logistic chain	• Lack of security and trustworthiness leading to sub-optimal Smart Systems
Reliability	• Good practice and high standards of comprehensive and preventive reliability assurance in Europe	• Concerns about SCADA industrial control systems, especially legacy systems	• Europe to become the trend setter in reliability for 2nd and 3rd generation Smart Systems	• Miniaturisation and multi-materials may exacerbate thermo-electro-mechanical stresses – fatigue, and failure
Threat mitigation and protection from danger		• Europe not a leader in IT solutions • 93% of large organisations had cyber violations	• Authentication schemes • Mobile security • Identity management	• Non-adoption of security-rooted European security and safety technologies
Safety	• EU silicon makers and OEMs are leading technologies and applications in the field of automotive data security	• Concerns about SCADA industrial control systems, especially legacy systems	• Safety-critical software • Resilience in vehicle electronics and telematics	• Physical control access: Machine-to-Machine, Internet of Things, Smart Grid
Encryption and Data Security	• World-leading research in cryptography • Large EU markets in ICT	• Dependence on US supply chain for cryptography and anti-virus products	• Universal smart & secure devices with personal data multi protocol and multi-applications	• Huge increase in cyber-crime and cyber-terrorism, IP espionage • Rapidly changing threats

Sub-sector	Priority actions	Longer term actions
Sector as a whole	• Coordination action on 21st century threats and related support of smart systems • Safety upgrade technologies to extend the duration of safe life	• Maintain and develop our skills in security and safety • Smart collation of developing threats and protection/countermeasures
Threat prediction and detection	• Protection profiles for smart applications • Smart methods to detect ageing of technologies • Hardware Trojans	• Bring security and safety techniques into developing embedded applications • Electromagnetic security • Understanding of behavior of masses, and appropriate smart approaches for safety and security measures
Reliability	• Ageing of smart technologies and embedding structure; related new accelerated lifetime tests • New packaging to cover the increase in temperature range of Power smart systems, to cope with thermo-(electro-) mechanical stresses interface, cracks, .. • European network of experts and institutions regarding Smart Reliability	• Integrated approaches to 'design for manufacturability', 'design for testing', and 'design for reliability' processes for Smart Systems • Define the minimum requirements on reliability research as part of future Smart System developments • Address diversity of materials combined with increased complexity of the system
Threat mitigation and protection from danger	• Protection profiles for secure and safe smart applications • Robust embedded systems, including smart hardware anchors, trusted boot and safe by construction embedded software	• Actions towards development, evaluations & methodologies for robust smart consumer technologies • Enforcing safety and security while integrating smart heterogeneous applications and networks
Safety	• Strengthened reliability and resilience through the design and manufacture of fault tolerant Smart Systems • Wide adoption of multi-core processors with smart HW/SW mechanisms for real time data protection • Safety at low cost	• Intercommunication mechanisms for systems integrating smart and not so smart sensors • Evolution of ISO26262 and standardization effort at European level for smart data security • Coordination on M2M security and safety
Encryption and Data Security	• Security by design of new connected embedded applications • Secure multi party use of Smart Systems, with protected data • Smart Systems support to Cybersecurity and Big data management in the cloud	• Formal proof of security and fuzzing in Smart Systems • Trustworthy manufacturing processes for Smart Systems, or based upon Smart Systems • Smart product watermarking and unclonable

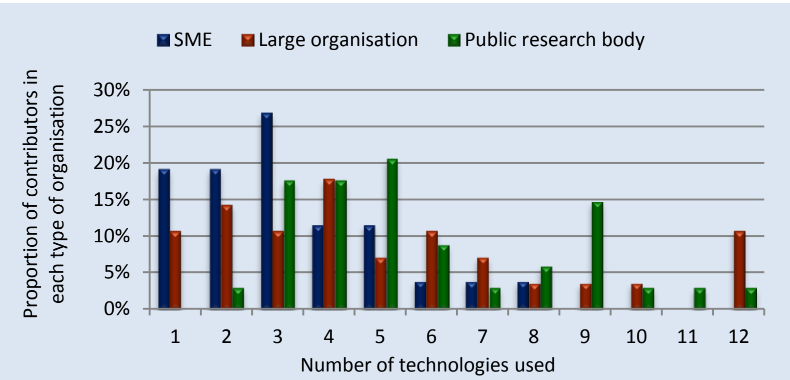
TECHNOLOGIES FOR SMART SYSTEMS



Technologies for Smart Systems



In the 2012 IRISS Smart Systems Technology Survey, 93 European Smart Systems providers including 30 Large companies, 29 SMEs and 34 Public research organisations, representing the supply chain from research through to market servers, showed engagement in a wide range of technologies (illustrated above).



Technology focus of organisations

Unsurprisingly, SMEs tend to focus upon a smaller technology toolset than large organisations, whose wider product offerings may address more markets.

Public research bodies typically span a greater number of technologies, reflecting the breadth of their research interests.

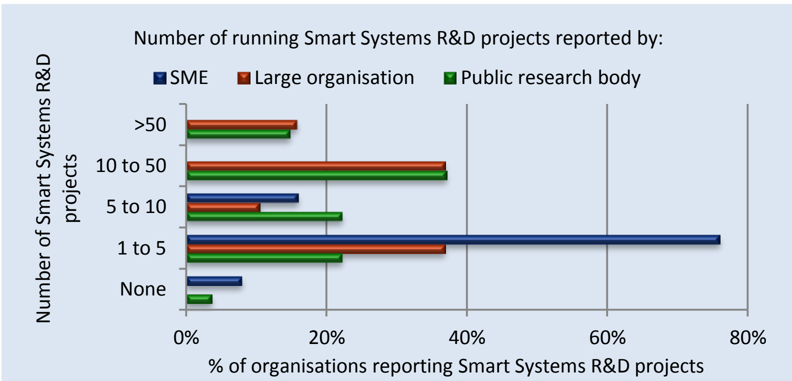
The data set (left) was derived from the 93 contributors to the 2012 IRISS Smart Systems Technology Survey

Research & Development activity

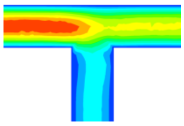
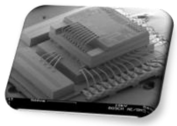
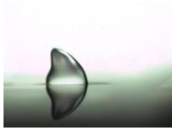
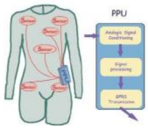
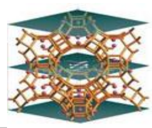
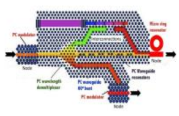
SMEs predominantly reported 1-5 Smart Systems R&D projects running in 2012, whereas the majority of Large companies and Public research bodies reported more than 10 projects, and in some cases more than 50.

Few correspondents reported no Smart Systems R&D projects running.

Forecasts for R&D activity are tabled in the individual technology descriptions presented later in this chapter.



The technologies in outline

Technology	Brief description	Application example	
Design & Simulation	Whilst Design & Simulation themselves are strictly activities, rather than technologies, they are bound into the technologies of manufacture, and computer-aided techniques are prevalent.	Design and simulation of microfluidic system *University of Greenwich*	
Micro- Nano- Bio- Systems (MNBS)	Micro- Nano- Bio- Systems (MNBS) combine highly miniaturised engineering and computer technologies with biochemical processes.	Labcard™ diagnostic system *IK4-IKERLAN*	
MEMS, MOEMS, Microfluidics	MEMS (Micro- Electro- Mechanical Systems) extend silicon technology to include sensors and mechanical movement. MOEMS (Micro- Opto- Electro- Mechanical Systems) extend the MEMS idea to include light sources and optical components. Microfluidics extend MEMS to the control and analysis of fluids	Microminiature eCompass *Bosch Sensortec*	
Semiconductors & More-than-Moore Technologies	"More-than-Moore" technologies add functions to normal semiconductor chips in ways not anticipated by Intel co-founder Gordon Moore of "Moore's Law" fame. These advances can allow chips, for example, to work directly with magnetics and fluids, and to communicate wirelessly.	Control of liquid droplets *Scottish Microelectronics Centre*	
Microsensors, microactuators	Microsensors can, for example, miniaturise sensing to such an extent that body functions can be monitored internally without disturbance – the "Lab-in-a-pill". Microactuators miniaturise movement and can, for example, be applied to active noise cancellation, antenna steering and adaptive optics.	Buccal Dose, a system for the oral application of drugs *HSG-IMIT*	
Combinational sensing	Human skin is a good example of combinational sensing, as it combines sensitivities to heat and pressure (touch). Combinational sensing provides similar, engineered, solutions in two ways: (1) combining discrete sensors or (2) using one sensor structure to measure several things.	Health & Usage Monitoring System (HUMS) *Heriot-Watt University*	
Large area sensors / actuators	Large area sensors/actuators take the technologies used for microminiaturisation but spread them over larger areas, (1) as large arrays of sensors, such as used in the CERN experiments and (2) as physically large sensors such as carpets for the medical investigation of how people walk.	Wearable Technology *WEALTHY IST-2001-37778*	
Multifunctional materials	Multifunctional materials can combine structure with a further function or functions. For example threads which sense heat or moisture could be woven into diagnostic pads for healthcare.	A large range of techniques *EMMI - European Multifunctional Materials Institute*	
Energy management & scavenging	Energy management & Scavenging technologies allow smart systems to make the most efficient use of resources and to gain their operating power from their surroundings.	Battery monitoring system *STMicroelectronics*	
Opto/organic/bio data processing	Memory and data processing in electronic computers is now routine. But new ways of data processing, using processes which "bio-mimic" the brain itself are under development.	Neuromorphic computer *femto-st*	
Adaptive surfaces	Human skin – already referred to under Combinational Sensing - is also an adaptive surface in that it can control temperature by wrinkling and raising hairs. Technology solutions can now make engineered surfaces that can for example change their aerodynamic properties through control of the boundary layer.	Advances in wind turbine technology *Siemens*	
Machine cognition & Human Machine Interfaces	As systems increase in complexity, human limits may constrain their use. Advances in Human machine Interfaces will relieve this situation, and devices that better "understand" the user will provide major advantages in ease and accuracy of operation.	Thales-designed ATR "-600" cockpit *Thales*	

Design & Simulation

Overview

Design spans from product conception, detailing how it works and is made, to issuing specifications which define materials, production processes, testing, and the product's ultimate use and disposal.

Modelling and Simulation aid the designer either by software modelling or the creation of "dummy" products illustrating aspects of the design to be reviewed and refined.

Whilst Design & Simulation themselves are strictly activities, they are bound into the technologies of manufacture, and today's complexity dictates that computer-aided technology is prevalent.

Importance for Smart Systems Integration

- Design puts the "Smart" into Smart Systems, at material level, sub-system level, at product level, and at user-system level
- Design captures the needs of users
- Modelling and Simulation are essential tools to understand the relationships between the multiple disciplines entailed in Smart Systems and their use

Hurdles to be overcome

- Design for Manufacture more critical because of mixed technology, small volume, customisation.
- Design: how to rank requirements for market acceptance – psychophysics will be important as users interact with "smart" products, and possibly through several senses simultaneously.
- Co-design of product and process will be essential when the product itself communicates with the production line during manufacturing.
- Need to develop better cross-discipline models in both design & simulation – extending to whole system engineering.
- Recognise a hierarchy of smartness. Where are the optimum points for intelligence?

Centres of excellence

CAD companies are mainly US-based, eg Flomerics (Mentor Graphics) R&D still in EU.

R&D Design and Modelling strong in EU universities and institutes. Greenwich University. Fraunhofer ENAS, Brunel University.

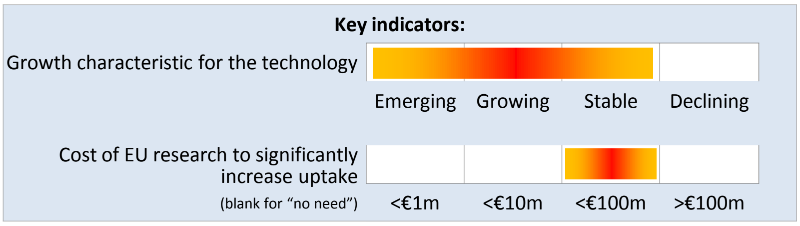
Prospects

Co-design is a hot topic with EDA vendors, and established customers.

Entry costs into sophisticated design systems are currently high for SMEs, but emergent crowd sourcing – connection across the supply chain and to users – could completely change the business model.

Impact

Improvements in Design & Simulation will bring a shorter time to market product cycle, more competitive solutions, and greater manufacturability, saving material and process costs and wasted resources.



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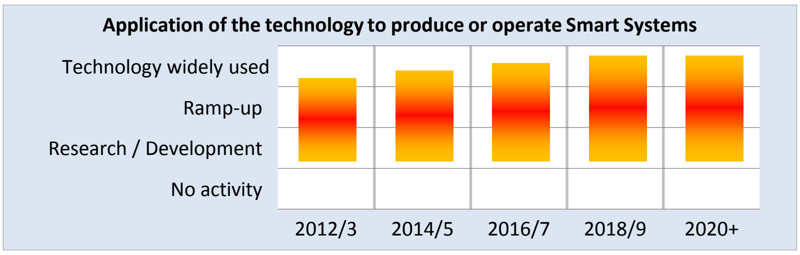


Quick links:

Technology overview | Design & Simulation | Large area sensors / actuators | Micro- Nano- Bio- Systems (MNBS) | Multifunctional materials | MEMS, MOEMS, Microfluidics | Energy management & scavenging | Semiconductors & More-than-Moore | Opto/organic /bio data processing | Microsensors, microactuators | Adaptive surfaces | Combinational sensing | Machine cognition & Human Machine Interfaces | EU Strengths & Research priorities

Micro- Nano- Bio- Systems (MNBS)

Overview

Micro- Nano- Bio- Systems (MNBS) combine highly miniaturised engineering and computer technologies with biochemical processes.

Front running applications are diagnostics, implants and surgical tools. Neural interfaces.

The use of MNBS technology can simplify and miniaturise processes compared with non-MNBS approaches. Moreover, MNBS promises approaches that are radically different to traditional concepts.

Importance for Smart Systems Integration

- Pathogen and micro-organism detection are front runners, followed by the detection of bio markers, pesticides, narcotics and explosives.
- Product benefits: Doing expensive things cheaply, smaller, immediately, and more reliably.
- Strongest applications in the long term are in food, air and water, then medical, agriculture.
- Societal / Environmental benefits – air quality, landfill

Prospects

Beyond the in-house developments of major corporations, many MNBS ideas are conceived of and developed by smaller groups. Their access to global markets may be limited, but there are good prospects for licensing.

Impact

Once MNBS technology is better established, there will be huge opportunities to expand its exploitation into environmental, food, air and water purity applications.

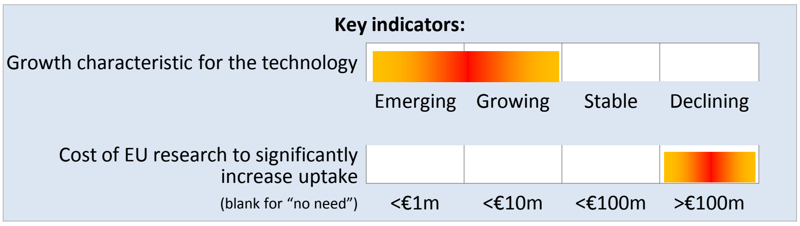
Hurdles to be overcome

- Combination of skills not easy to find.
- Patents and secrecy slowing commercialisation
- Not a building block (modular) approach yet.
- Differences in scale from nano to micro to macro.
- Large differences in the volume/price equation.
- Biocompatibility.
- Biostability.
- Integration into wider systems.
- Smart microfluidics.
- Integrated sample preparation.
- Design and development of life-mimicking bio sensors, building on new knowledge by the "engineering" instrumentation now provided to biologists.

Centres of excellence

Strength in Singapore and the US (Wyss Institute).

The current EU position is strong in research publications, but not in commercialisation.



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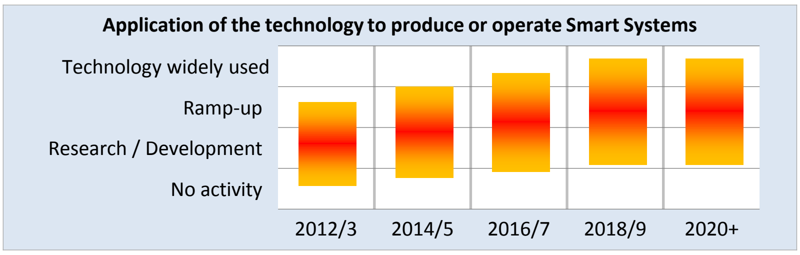

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MEMS, MOEMS, Microfluidics

Overview

MEMS are Micro- Electro- Mechanical Systems. They extend silicon chip technology to include sensors and mechanical movement, providing opportunities to make functional machines at the micro- scale.

MOEMS are Micro- Opto- Electro- Mechanical Systems which extend the MEMS idea to include light sources, and optical components and sensors.

Microfluidics extend MEMS to the control and analysis of fluids.

Importance for Smart Systems Integration

- Applications are exploding with introduction of smartness into every walk of life.

Centres of excellence

US-driven (used to be driven by DARPA – this created a capability base).

US drive for portable devices.

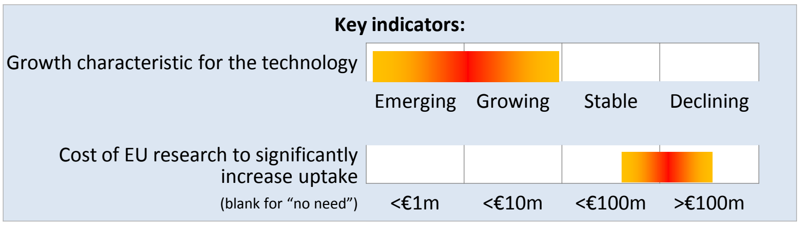
Hurdles to be overcome

- Manufacturing technologies need to migrate to non-silicon route if smaller batches are to be made at lower cost.
- Optics and microfluidics are outside the range of experience of the majority of micro-electronic focussed designers and manufacturers.
- Optics present a great but difficult opportunity for miniaturisation/integration - how to shrink or simplify “classical” components.
- In microfluidics, “the manifold” is the issue – how to match fluid handling at the micro scale to applications at the macro scale.
- Energy autonomy
- MEMS modelling and applications-specific packaging. Testing and characterisation of devices at the micro-scale, and of constraints exerted at the meso-scale.
- Reliability needs further research (physics of failure), as well as the behaviour of new materials and combinations of materials.

Prospects

Microfluidics promises great benefits, but is early in its exploitation curve.

Optical integration is also nascent, but potentially vital in respect of high bandwidth communication within Smart Systems, and between Smart Systems (concept of optical backplane).



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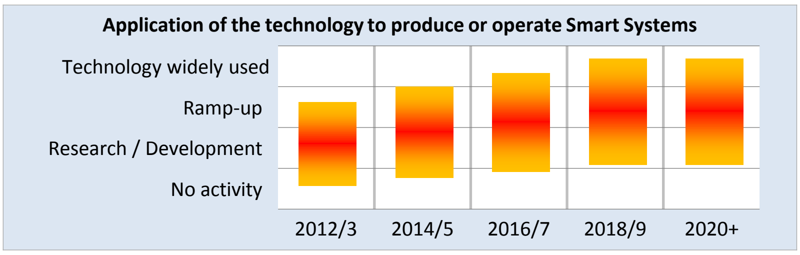
Impact

From a technology point of view, MOEMS research is creating solutions often “waiting for a problem”.

Promotion of these capabilities, to designers and in proper dialogues with markets and users, could bring about a tipping point for exploitation.



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Semiconductors & More-than-Moore Technologies

Overview

More-than-Moore technologies integrate functions to normal semi-conductor chips in ways not anticipated by Intel co-founder Gordon Moore of “Moore’s Law” fame. These advances can allow chips, for example, to work directly with magnetics and fluids, and to communicate wirelessly.

Importance for Smart Systems Integration

- Integrated power supplies and power management
- Embedded optical intercommunication.
- Stacked chips can combine complimentary technologies.
- Sensing and actuation may be integrated with local processing.
- 3D-integration allows reduction of footprint and volume compatible with MNBS.

Hurdles to be overcome

- Few standard processes
- Stresses in materials, because Smart Systems typically use multi-materials.
- Generally depends on mass-produced chips as “substrates”. Sometimes need bigger chips for pot-processing than this “economical” size.
- Requires packaging and bonding technologies compatible with the materials’ behaviour with changing temperature and other environmental conditions.

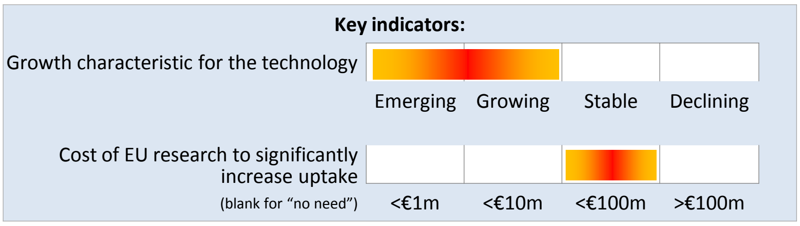
Centres of excellence

International centres for the technology: Georgia Tech, A-Star.

The current EU position: Fraunhofer IZM, Scottish Microelectronics Centre, IMEC, VTT, CSEM.

Prospects

Technology already widely used in photographic image sensors, optical capsule endoscopy (Pillcam).



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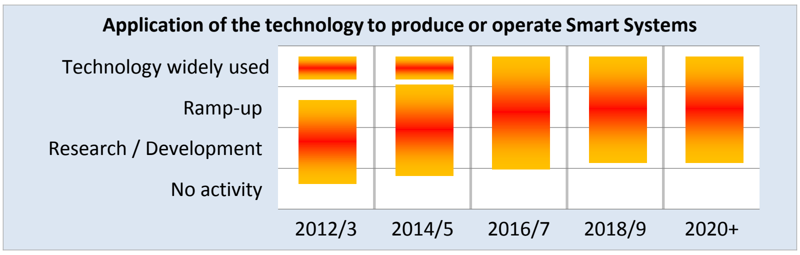
Impact

Some niches cannot be satisfied any other way, for example portable multifunctional biosensing, customising for economies of scale.



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Microsensors, microactuators

Overview

Microsensors and microactuators can, for example, miniaturise sensing and movement to such an extent that body functions can be monitored internally without disturbance – the "Lab-in-a-pill".

Distributed microsensors can provide reliable detection through cross-calibration and networked corroboration. Magnetics, EMF, THz, microwave, radioactivity. Size might be limiting

Distributed microactuators can for example be applied to active noise cancellation, antenna steering and adaptive optics.

Importance for Smart Systems Integration

- Sensing and actuation are fundamental to Smart Systems
- Micro-scale sensors and actuators are easier too integrate with other micro-scale structures
- At the micro- scale, sensors may gain abilities of sensitivity and specificity not easily achievable at macro dimensions.

Hurdles to be overcome

- Actuators difficult to scale from macro sized counterparts.
- Integration of moving parts is difficult – fracture, work hardening.
- Understanding materials behaviour at low dimensions.
- Autonomy – energy.
- Ability to work in harsh environments.
- Failure modes need to be better understood.
- In-built diagnostics and prognostics, self-adaptation and self-validation.

Centres of excellence

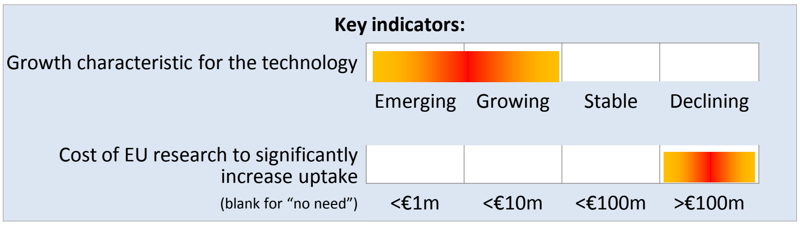
A large number of different fields, so international and EU centres for the technology, its development, and deployment are difficult to distinguish.

University of Lancaster, University of Greenwich, Calce (University of Maryland, US) for sensors diagnostics and prognostics.

Prospects

Smartphones and tablet computers already feature smart systems based upon accelerometers and pressure, temperature and image sensing.

Microactuators are not so well developed, except for the cases mentioned below. Steerable antenna arrays will be important for connecting with the Internet of Things.



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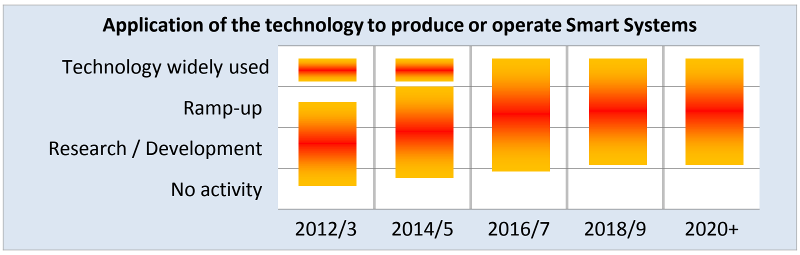
Impact

Previous examples have enabled displays, (eg the TI micromirror) inkjet printing, fuel injection.

The future can see artificial organs, cochlear implants, haptics and robotics.

The deployment of autonomous drones will accelerate uptake significantly.



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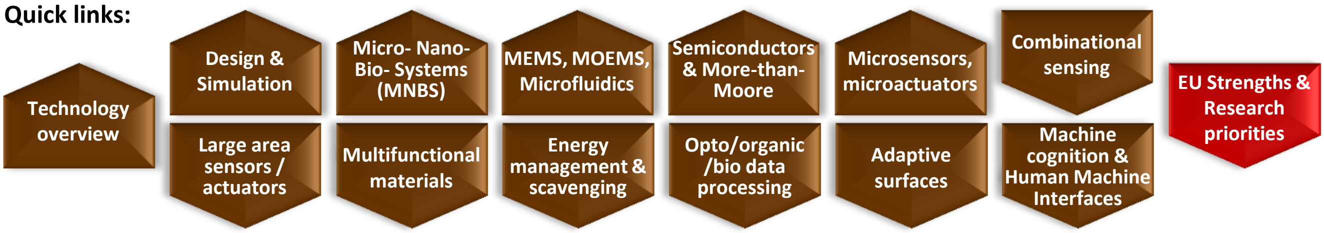


Combinational sensing

Overview

Human skin is a good example of combinational sensing, as it combines sensitivities to heat and pressure (touch).

Combinational sensing provides similar, engineered, solutions in two ways: (1) combining discrete sensors or (2) using one sensor structure to measure several things.

Importance for Smart Systems Integration

- Smartness is critical for the combinational output to be useful.
- Applications in multidimensional scenarios, such as health – chemical, electropotentials, heat, and pressure.
- Combinational sensing will underpin multimodal interaction - communication through sound, vision, smell and touch. This will unleash new markets.

Hurdles to be overcome

- Developing the multi-dimensional "cognitive" aspects.
- Sequence and hierarchy of data reduction.
- A mathematical framework for data fusion will be important for processing from data to information to decision.

Centres of excellence

International centres for the technology: Agilent

The current EU position: Femto, Thales, Selex, Heriot-Watt University (Prognostics and health Management), Imperial College, University of Loughborough (Body sensor network).

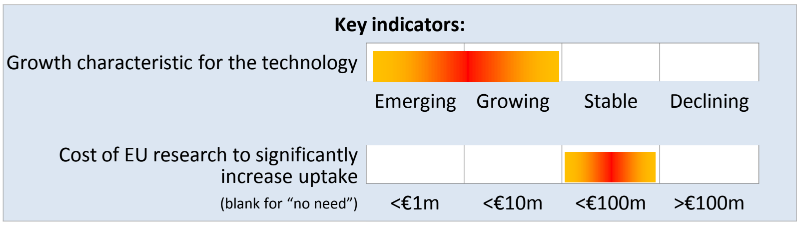
Prospects

Smartphones already demonstrate sensing combined with a display as an integrated system.

Interaction with the environment, safety, and security present increasing challenges to be addressed by sensing multiple parameters and inferring situations.

Impact

Combinational sensing will underpin Health & Usage Monitoring Systems (HUMS), which are forecast to grow rapidly in application to extend the life of existing structures - including airframes - and new complex structures and systems that need to operate closer to their theoretical limits.



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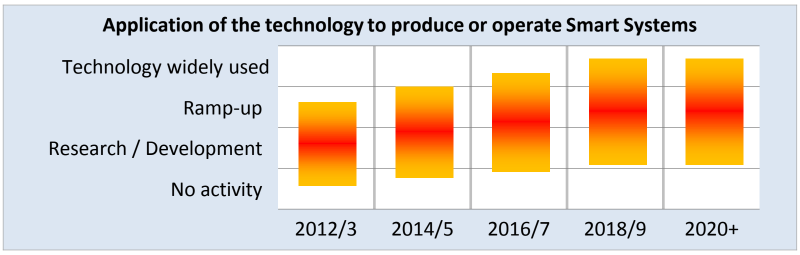

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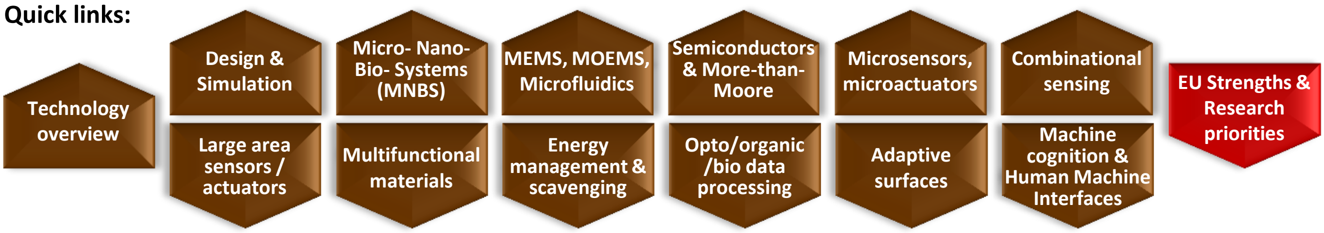


Large area sensors / actuators

Overview

Large area sensors/actuators take the technologies used for microminiaturisation but spread them over larger areas.

(1) As large arrays of sensors, such as used in the CERN experiments and (2) as physically large sensors such as carpets for the medical investigation of how people walk.

Importance for Smart Systems Integration

- Large area sensors will take Smart Systems into clothing & textiles and the built environment.
- Large arrays of similar sensors will be enabled by Internet of Things networks.
- Large area sensor/actuation may be integrated into larger structures, such as PV panels or wind turbine blades.

Hurdles to be overcome

- Manufacturing capability for large area products.
- High performance and reliability under harsh conditions – large area systems may be difficult to repair or replace.
- Fault tolerance of large area systems.
- Inter-operability and data fusion.

Centres of excellence

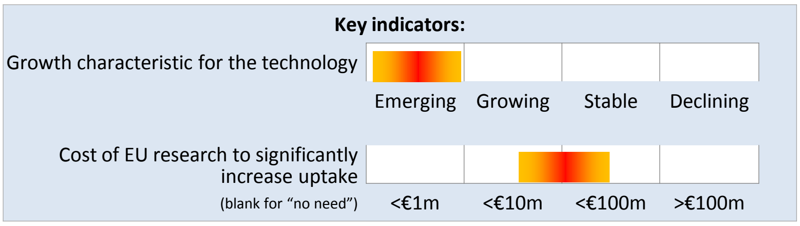
International centres for the technology: NTU, Polytechnic University of Hong Kong.

The current EU position: Research at IMEC and Fraunhofer IZM, Philips, ENAS, Femto-ST (distributed MEMS).

Prospects

Roll-to-Roll processing will take Smart Systems into large area applications such as adaptive wind turbine blades (adaptive surfaces) and steerable PV arrays.

Arrays of plantable "Smart Seeds" will aid agriculture.



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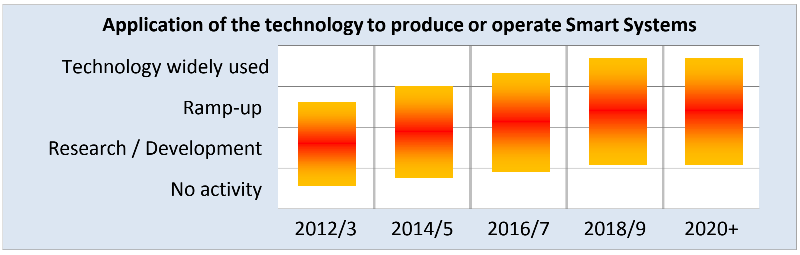
Impact

Security of industrial plants and public spaces.

Intelligent environments, particularly helpful for an ageing population.

Smart textiles and clothing.

Precision agriculture.



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Microsensors, microactuators
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Machine cognition & Human Machine Interfaces
EU Strengths & Research priorities

Multifunctional materials

Overview

Multifunctional materials can combine structure with a further function or functions.

For example threads which sense heat or moisture could be woven into diagnostic pads for healthcare. Shape memory materials / alloys are another example, combining structure with actuation.

Importance for Smart Systems Integration

- Multifunctional materials offer to provide true integration – combining sensing, energy storage and actuation, and potentially also memory and logic functions.
- Coupled with additive manufacturing, multifunctional materials offer a low cost, agile and versatile entry to smart manufacturing.

Hurdles to be overcome

- No standards for materials that intentionally vary.
- Metamaterials – so many possibilities, but no clear progression for application.

Centres of excellence

International interest in the aerospace sector, particularly for structural energy storage in satellites.

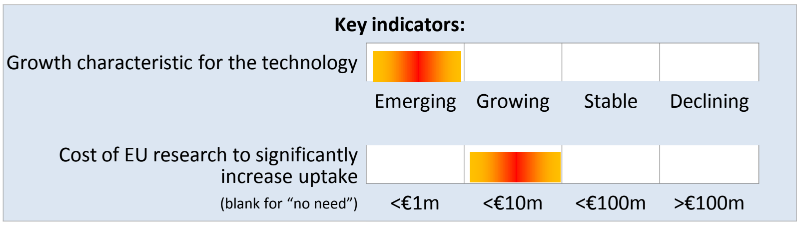
A network, The Center for Multifunctional Materials and Structures, is coordinated by UC Santa Barbara.

In Europe, many centres including EMMI - European Multifunctional Materials Institute, the Centre of Innovative manufacturing in Additive Manufacturing (Loughborough-Nottingham).

Prospects

Multifunctional materials could be carefully formulated to replace, reduce the use of, or share the use of, scarce materials.

Combining functions with structures will save weight and materials.



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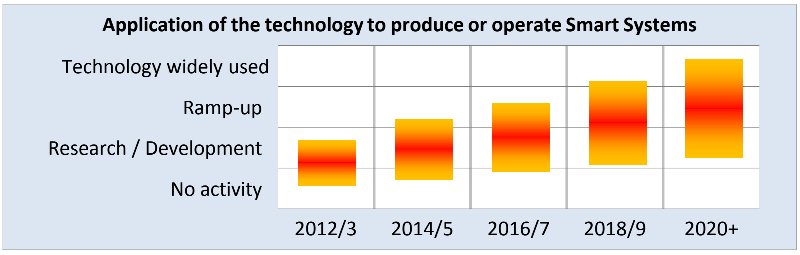
Impact

Smart structures – for example automotive panels that also store energy – will revolutionise products, whilst also reducing the number of manufacturing processes and reducing complexity.



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Energy management & scavenging

Overview

Energy management & Scavenging technologies allow smart systems to make the most efficient use of resources and to gain their operating power from their surroundings.

Importance for Smart Systems Integration

- Adaptive distributed energy management, eg in-battery cell monitoring, in-sensor monitoring, in-network monitoring
- Passive sensors such as energy-less and untethered (wireless) sensors.
- Poll-on-demand wirelessly powered sensing.
- Smart cards.
- Use-once systems.

Hurdles to be overcome

- Scavenging from motion, thermal gradients, electromagnetic fields (including light and hyperspectral light), chemical reactions, biological processes, Casimir effect.
- Energy storage is a major factor: scavenging is typically little but often, whereas use is more but infrequently.
- Self-consuming systems that convert their substance into energy while performing their role, leaving an inert remainder at end-of-life.

Centres of excellence

International centres for the technology not recognized.

No identifiable major industrial products, beyond watches, calculators.

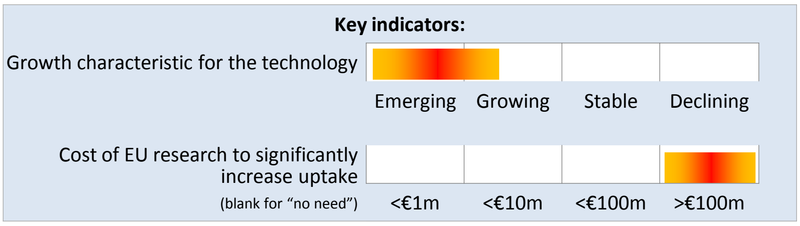
The current EU position: CEA Liten, FEMTO-ST Imperial College UK.

Prospects

Miniaturised energy management systems have been a feature of portable battery-powered systems for many years, and have become very sophisticated, but largely at component-level rather than system level. Scavenging solutions have remained relatively rudimentary to date although the issues for advancement are known.

Impact

Fully integrated energy management and scavenging is the enabler that will allow portable, body-worn and autonomous systems to proliferate in every sector



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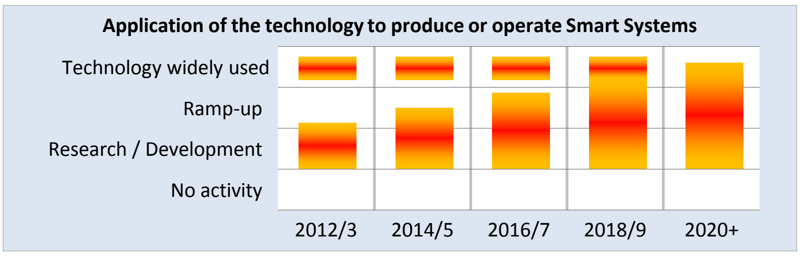

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Opto/organic/bio data processing

Overview

Memory and data processing in electronic computers and systems is now routine. But new ways of data processing, using processes which “bio-mimic” nature, the brain itself, and other physical effects are under development, including also photonics-on-silicon and quantum dot s.

A bacterial logic gate has already been engineered to take its input from two natural sensors in a bacterial cell that detect different sugars in its environment. If these particular inputs are present it produces an output in the form of a fluorescent protein. In the future, such a cell could detect pollutants and take action to neutralize them.

Importance for Smart Systems Integration

- Non-electronic data processing may be better suited to the pattern-based information gathered by large networks of sensors, perhaps also including several domains of sensing, as in humans.
- Non-electronic processes may use less power.
- Potentially an answer to data condensation for complex smart systems.

Hurdles to be overcome

- Better understanding of fundamental logical and control processes in the bio domain.
- Photonics-on-silicon.
- Quantum dot processes.
- Understanding system control problems from a non-electronic perspective.
- Finding user pull.

Centres of excellence

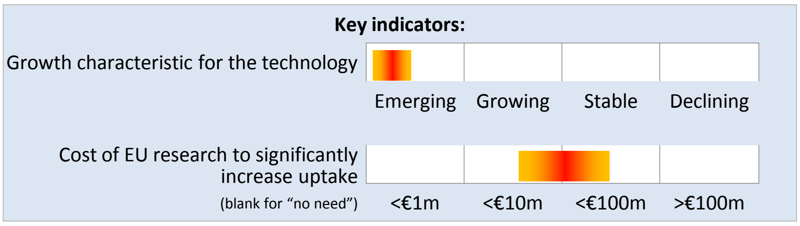
The current EU position: Femto ST.

International Centre for photonics on silicon: Intel.

Prospects

One example is a neuromorphic photonic processor, in development, based upon non-linear crystals and capable of miniaturisation.

Such approaches can provide control for, eg the prognostic management of fuel cells, and forecasting catastrophic events, in weather, finance.



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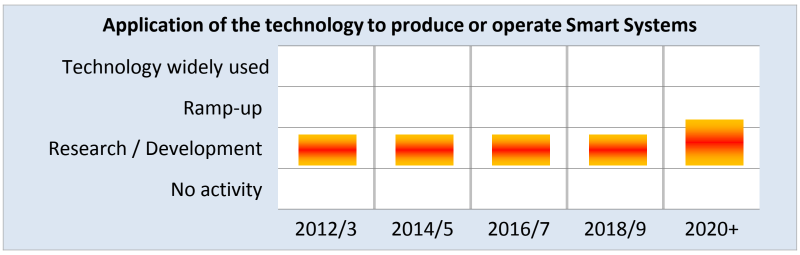
Processing pattern-based information, or information difficult to classify, gathered by large networks of sensors will benefit from such breakthroughs in processing architecture, perhaps as co-processors alongside more conventional approaches.



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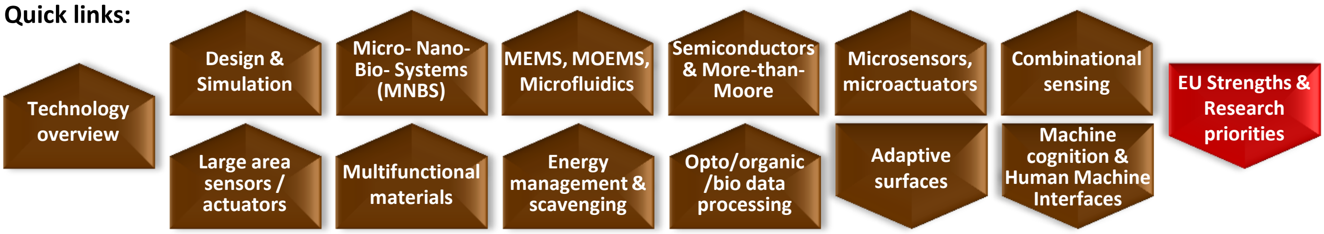


Adaptive surfaces

Overview

Human skin is an adaptive surface in that it can control temperature by wrinkling and raising hairs.

Technology solutions can now make engineered surfaces that can for example change their aerodynamic properties through control of the boundary layer.

Another example is the control of surface properties regarding liquids, this has led to the manipulation of droplets, transporting, mixing and separating them.

Importance for Smart Systems Integration

- An extension of large area sensor/actuator arrays to include actuation by surface deformation or changes in its physical parameters.
- Opens new possibilities for the control of gases and liquids.
- Opportunities for adaptive optics and adaptive antennas.

Hurdles to be overcome

- Has to survive environmental “abuse” as surface structures are exposed.
- New characterisation of functions and materials properties, including also durability and reliability – parallels with Multifunctional materials.

Centres of excellence

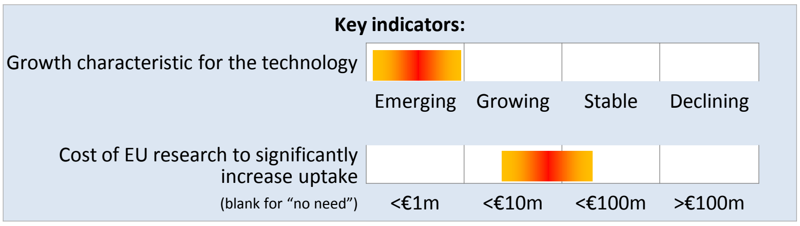
International centres for the technology: Aerospace companies, Duke University (Digital microfluidics).

The current EU position: Scottish Microelectronics Centre, CEA-Leti, University of Glasgow.

Prospects

Functional surfaces promise wide new classes of products - self-healing, self-cleaning, communication of (and by) textures, controlled friction, adaptive optics and antennas.

Moreover, there is potential for new process controls in biological cell growth, sorting and manipulation.



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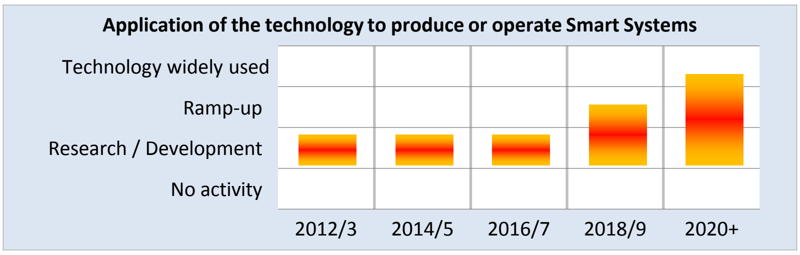
Impact

The above prospects will lead to:

- Reduced maintenance costs in PV systems, buildings, aerospace.
- Enhanced personal communications.
- Higher energy efficiency.
- Advances in medicine.



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Machine cognition & Human Machine Interfaces

Overview

As systems increase in complexity, human limits may constrain their use. Advances in Human Machine Interfaces (HMI) will relieve this situation, and devices that better "understand" the user will provide major advantages in ease and accuracy of operation.

Importance for Smart Systems Integration

- Extends Smart Systems' capabilities regarding awareness of environment and self-adjustment.
- Reduces intervention of human operator for repetitive or critical (and time critical) tasks.
- Allows exploration of inter-operability of various systems components without the sometimes erroneous human preconception of the optimum functionality of a system.

Hurdles to be overcome

- Better understanding of how machine learning can adapt to user needs and habits.
- What is the right level of "challenge" that should remain in the human/machine control relationship.
- How to transport "cognition" into hazardous environments beyond the experience of humans.

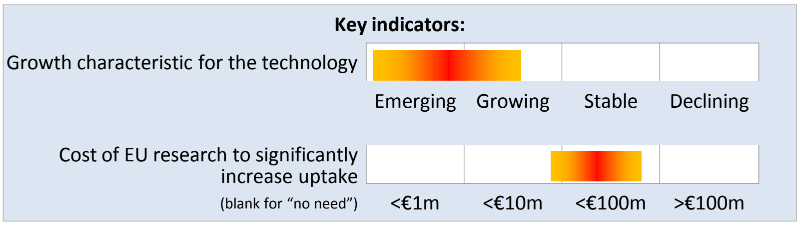
Centres of excellence

International centres for the technology: US DoD.

The current EU position: Thales (aerospace cockpits), Heriot-Watt University (Haptics and Digital Tools).

Prospects

Machine Cognition will ultimately take Smart Systems to the 3rd generation – where Smart Systems themselves simulate human perception/cognition.



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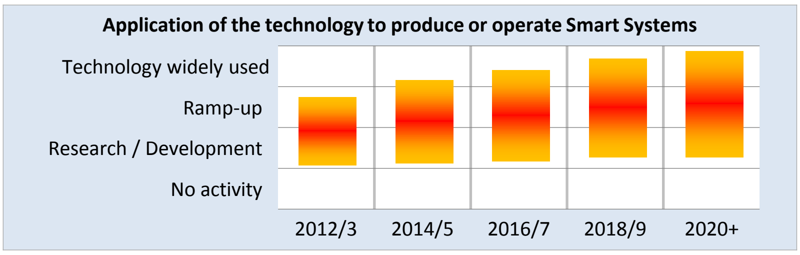
- Products that understand and better satisfy human needs.
- Advances in telemedicine.
- Smart homes for less able people.
- Safety enhancements in aerospace cockpits, nuclear control panels.



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Technologies for Smart Systems: European position

Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Technologies overall	• Big established companies • Materials knowledge • Strong research base	• Conservatism in investment • Big companies risk averse	• Advanced technologies enable new products	• Low cost manufacturing
Design & Simulation	• Good multidisciplinary R&D effort particularly universities • Global focus for conferences • Culture of complexity • Product design can compensate sometimes for weak technology	• US ownership • Not on EU or Member State agenda • Not seen as an "engineering" discipline	• Develop fully integrated approaches, including cloud connectivity • Consolidate supply chain through design • Licence and IP income	• Cloud connectivity can be used by anyone • EU skills base reducing and migrating away • Manufacturing experience moving outside EU
Micro- Nano- Bio-Systems (MNBS)	• Collectively, EU has a good knowledge base in MNBS • Meet EU societal changes challenges	• Not a universally taught discipline of Smart System Integration • Low volumes • Big investors are secretive	• Develop cost effective low volume production	• Current funding mechanisms discontinue
MEMS, MOEMS, Microfluidics	• Innovative R&D, with a great number of capabilities already on the shelf • Diversification of markets		• Some niches can be brought to maturity. eg RF MEMS, switching • Telecoms opportunity for optical devices	• World catching up (eg, DARPA funding on microfluidics for chip cooling)
Semiconductors & More-than-Moore Technologies	• Semiconductor know-how • IP can be kept secure	• Base advanced semiconductor technology largely outside the EU	• Some niches cannot be satisfied any other way • Non-silicon semiconductors as basis for high power, harsh environments	• Low cost entry for competitor regions to undermine established, sophisticated EU products
Microsensors, microactuators	• Hidden champions in a variety of companies eg SKF • Major players eg ST, accelerometers • Good base in active materials	• The champions are hidden	• Migrate technology from one company or one sector to another • IP brokerage for sensors • Broaden use environment	• Globally, More-than-Moore will impact this domain. EU must maintain its momentum
Combinational sensing	• Thales, Selex • Huge range of applications	• Fundamental research needed	• Combine sensor and system groups	
Large area sensors / actuators	• CERN • Fraunhofer IZM, ENAS • IMEC	• Basic and high volume materials are manufactured outside EU	• Service industry in installing and running large networks • Manufacturing equipment	
Multifunctional materials	• Strong research base in materials science	• Materials science isolated • Risk averse to disruptive technologies • Current "electrical" culture has difficulty interfacing to other approaches	• Bridge from materials science to products (how to inform designers?) • Disruptive approaches	• Poor simulation, product recalls • In disruptive technologies, winner takes all – but may not be in the EU.
Energy management & scavenging	• On-chip management well established • Lots of research and start-ups in energy scavenging	• Low commercialisation of energy scavenging	• Need killer application for energy scavenging	• US DARPA financing strongly
Opto/organic/bio data processing	• Research strong	• Finding user pull	• Expose to users	• Breakthrough research funding outside the EU
Adaptive surfaces	• Culture of innovation	• Conservatism for exploitation	• Create new markets • Upgrade/prolong existing structures	
Machine cognition & Human Machine Interfaces	• Strong in design • Strong in cognitive science	• Lost between disciplines • Not on EU Commission agenda	• Strengthen links to other engineering disciplines	• Cyber engineering is on the US agenda

Technologies for Smart Systems: Research priorities

Sub-sector	Priority actions	Longer term actions
Overall	•System integration culture	•Education: Inspire and create engineers of tomorrow
Design & Simulation	•Gain recognition as an engineering topic for funding •Smart Systems design methods emphasising market acceptance of intelligent products •Smart Systems case exercises involving supply chains •Design teams need to know where the EU Smart Systems manufacturing capability is	•Education: attract multidisciplinary designers •Retaining designers in the engineering sector •Develop new business models
Micro- Nano- Bio- Systems (MNBS)	•Biocompatibility •Biostability •Integration into wider systems •Smart microfluidics •Integrated sample preparation	•Learn from how life self calibrates and self heals •Design and development of bio sensors, building on new knowledge brought about by the "engineering" instrumentation now provided to biologists
MEMS, MOEMS, Microfluidics	•Flexible approaches to manufacturing, business and the ability to mix/match/modify processes •Interface to other system parts, packaging	•Need to keep designers and marketeers up-to-date with the developing capabilities of MOEMS
Semiconductors & More-than-Moore Technologies	•Need to understand mass production, transferring from "similar" processes •Develop processes with non-silicon semiconductors as basis for high power, harsh environments	•Develop manufacturing supply chain
Microsensors, microactuators	•Understand active materials •Broaden the range of sensor applications, their sensitivity and their specificity	•Build a register of types and availability •Integrate with IoT infrastructure
Combinational sensing	•Fundamental research aimed at revealing the new capabilities arising from miniaturised structures •Large IP project needed, plus FET open projects •Links to cognitive research	•Development of a recognisable supply chain •Scope roadmap for variety of application and set up actin plans and funding
Large area sensors / actuators	•Identify rewarding applications •Demonstrator projects	•Integrate with Smart Cities, Smart Grids as examples
Multifunctional materials	•Create a "Genome of materials" •Become less dependent upon "electrical" viewpoints •Research the life cycle and durability of such materials •Integration of energy storage	•Multifunctional materials carefully formulated to replace, reduce the use of, or share the use of, scarce materials •Research naturally inspired manufacturing
Energy management & scavenging	•Survey of who is actually doing what in energy scavenging. What is the current practical position? •Determine the most appropriate for Smart Systems. •Identify/establish a focal point, network or centre	
Opto/organic/bio data processing	•Identify drivers •Protect skill base •Long term funding required	
Adaptive surfaces	•Needs progressing out of the lab and into the field	
Machine cognition & Human Machine Interfaces	•Strengthen links to cognitive research •Better understanding of how machine learning can adapt to user needs and habits •How to transport "cognition" into hazardous environments beyond the experience of humans	•Discussion of ethics

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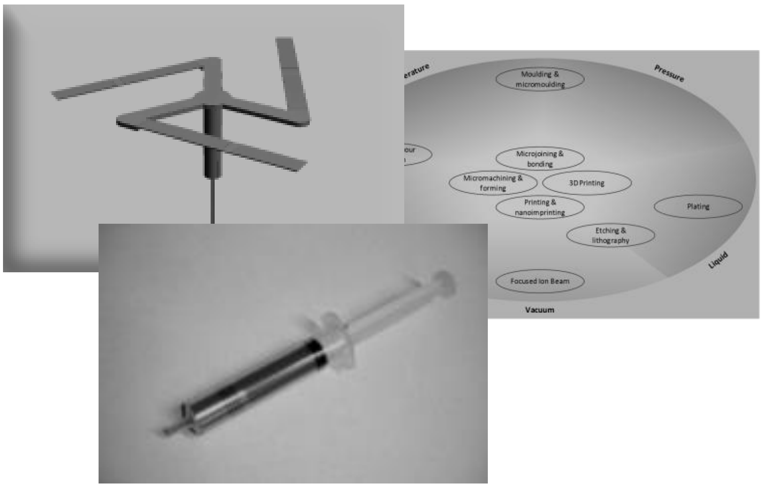
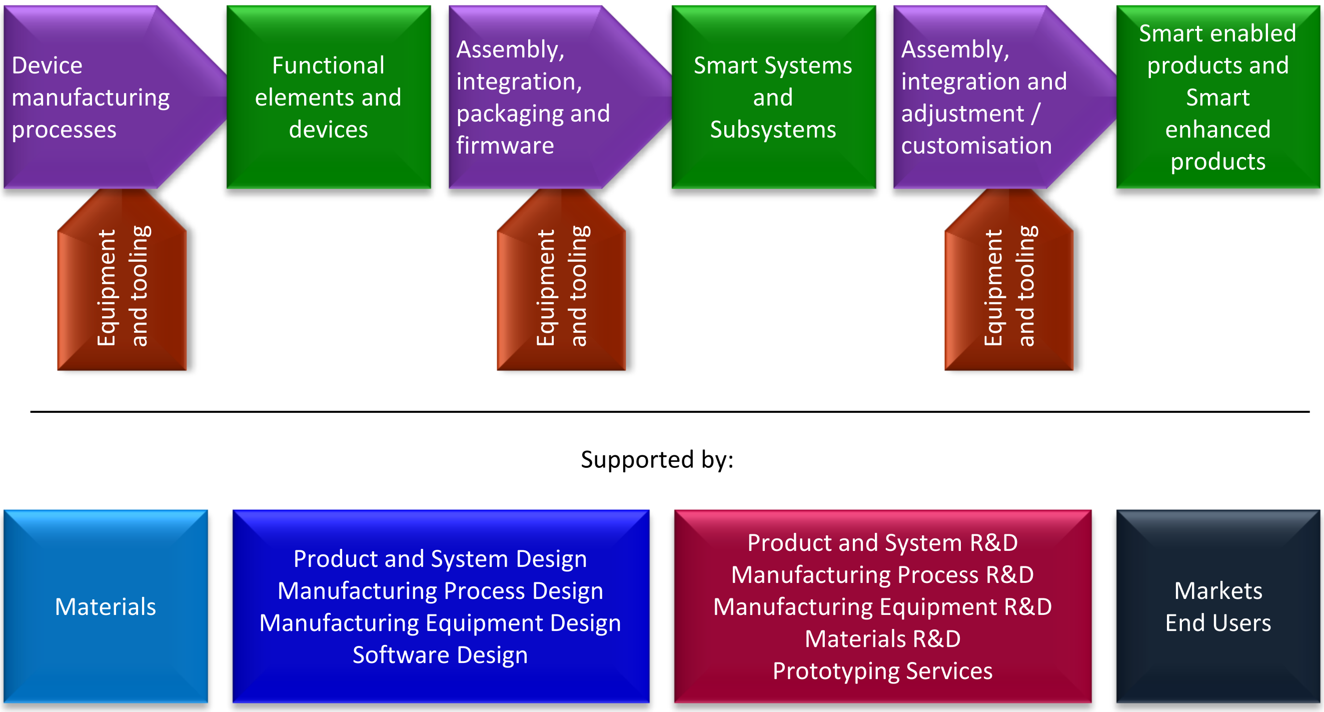
PRODUCTION PROCESSES FOR SMART SYSTEMS



Production Processes for Smart Systems

Manufacturing supply chain



Introduction

A typical manufacturing activity spans from design to dispatch. Incoming raw materials and parts are converted by production processes into tested end products, or part-finished items further up the product hierarchy (for example an aircraft wing is a complex combination of structure and sub-assemblies, and yet is not an end product in itself).

Essential ancillary activities to the production line itself are the logistics of materials, parts and energy supplies, the management of waste and effluent, and a planning process that orchestrates the elements of the process, the just-in-time provisions of suppliers, and the delivery schedules of customers.

Breadth of processes for Smart Systems

Smart Systems necessarily combine multiple materials and technologies to deliver the sensing, predictive and reactive actuation, data storage, cognitive, energy sustaining and networking aspects that are expected of them.

Spanning this breadth requires a broad range of processes, many of which are individually well-developed but not necessarily fully proven when combined to create highly integrated products.

A breadth of challenges

The following chapter examines 10 primary categories of production process:

- Etching & lithography
- Printing & nanoimprinting
- Micromachining, forming & handling
- Microjoining & bonding
- Moulding & micromoulding
- Deposition & coating
- Encapsulation
- Direct manufacturing & Rapid prototyping
- Test & inspection
- Repair & recycling

Each presents differing development challenges, but an over-riding priority is identified across all the processes:

- To encourage product-led access to advanced processes, and *combinations* of advanced processes.

Product-led development in such a knowledge-rich environment will be fertile ground for a truly European manufacturing supply chain and the involvement of agile, innovative, SMEs.

Vision: Smart Systems made by Smart Systems

The controlling inputs to a modern production line are data sets from CAD systems that generate tooling, manufacturing procedures and machine settings, and production planning systems that manage the flow of items appropriately according to the availability of raw materials, the varying requirements of different customers, and the reduction of waste and dead time.

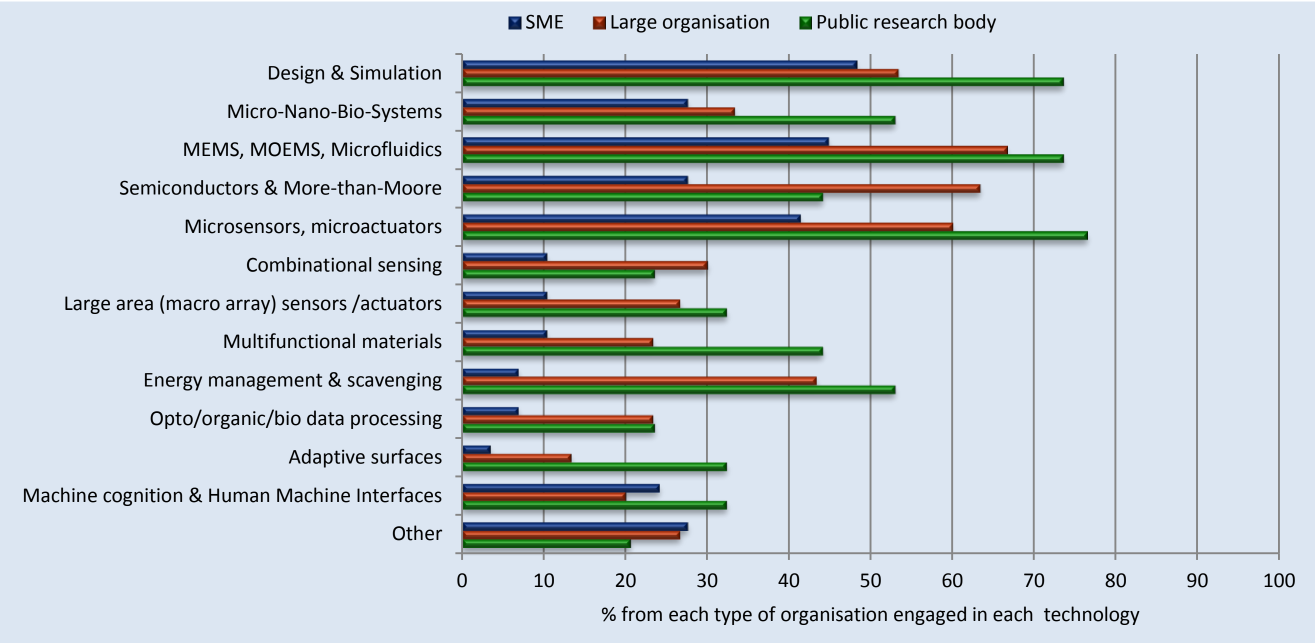
Current factory automation rests with well-developed control algorithms, which can only be effective when fed back with observations from the reality of on-machine sensors, human reporting and the statistical analysis of test results at the various stages of production, which culminate not just in final test but also upon customer acceptance procedures.

Today's on-machine sensors and in-line and end-of-line test equipment share fairly-well developed standard data interfaces but tend to present compromises in terms of their physical integration into the production line itself. Moreover, these sensing and testing activities "know" nothing of the finesse of manufacturing, nor the intricacies of the application of the end product, but simply send measurements to the factory management system.

Accordingly, the opportunity to "smarten" factory automation is clear:

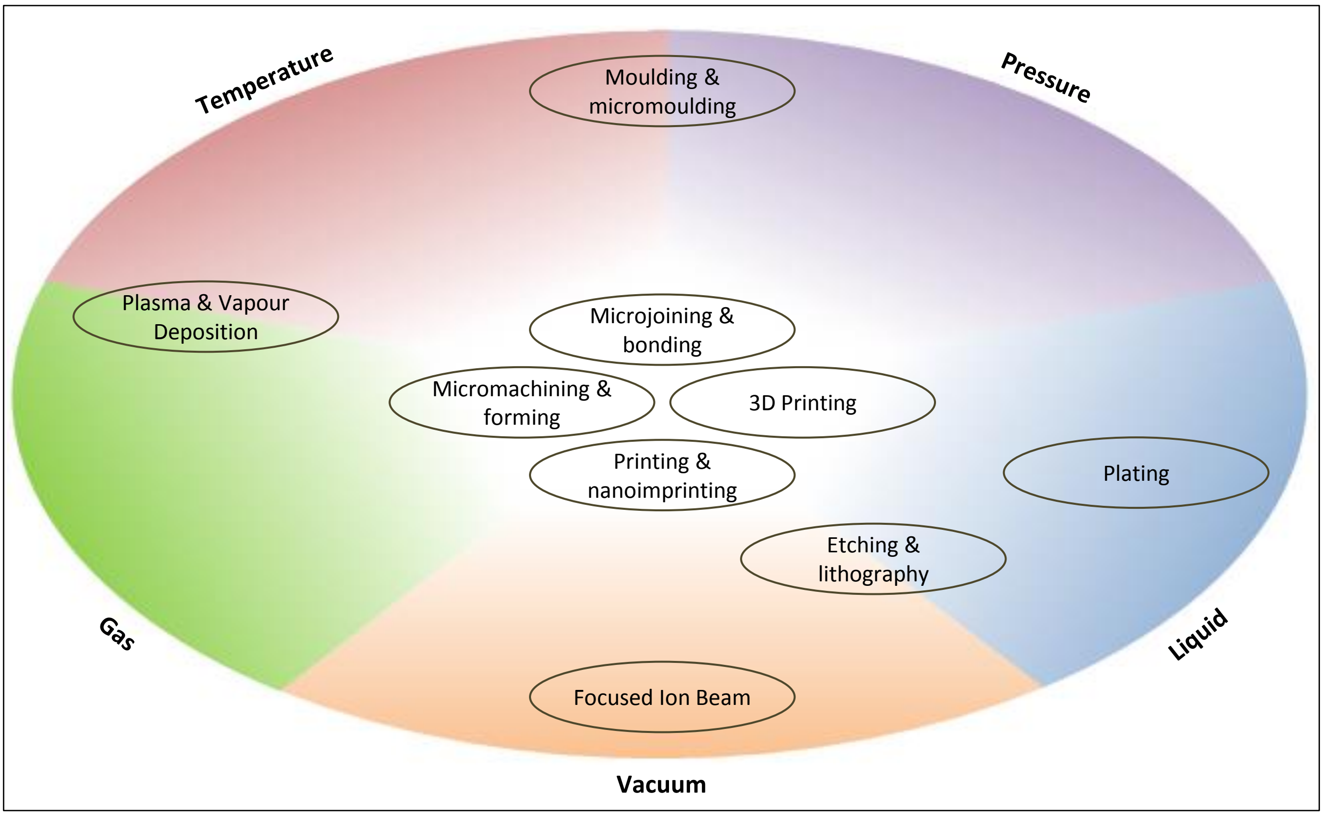
- Smart Processes that can interact with the Smart Systems that they produce promise to open the path towards products that themselves optimise the use of manufacturing materials and energy used in their production.
- They will optimise the route through subsequent integration processes and onward through logistics systems to the customer, ultimately eliminating manufacturing disruption and uncertainty, repairing faulty products as they are processed, increasing production yields, and accelerating the pace of the economy.
- The possibility exists to embed firmware instructions to allow a Smart System to customise itself according to variations in its own manufacture – variations in process conditions and materials – and potentially, through networking, to draw upon the "experiences" of other Smart Systems that have already passed along the production line or even embarked upon their working life.

Underlying technologies



In the 2012 IRISS Smart Systems Technology Survey, 93 European Smart Systems providers including 30 Large companies, 29 SMEs and 34 Public research organisations, representing the supply chain from research through to market servers, showed engagement in a wide range of technologies (illustrated above).

Prospects for process integration



As revealed by the IRISS survey, the wide range of technologies that may be incorporated within Smart Systems underlines the breadth of production processes that may be required in their integration.

The choice of production processes greatly influences product design, the chosen working principle of the product, the materials used and of course the overall cost of manufacture.

Desirable properties of production processes

Professor Marc Desmulliez of Heriot-Watt University suggests that for Smart Systems the ideal choice should be not only for integrative processes but also for integratable processes.

- Integrative processes can integrate multiple materials and can precede or follow other processes sequentially.
- Integratable processes can operate within a common manufacturing environment, and may be sequential or act upon the product simultaneously if required.

Additionally, processes for the production of Smart Systems need:

- Abilities to control interactions between multiple functionalities and to protect sensitive elements against interaction with the production environment
- Abilities to reduce the number of interfaces, particularly in sensing and specialised packaging.

Taxonomies of production processes

A framework will be helpful in the selection of processes.

The conventional approach is to classify processes according to the following general classes:

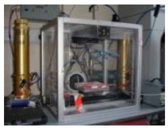
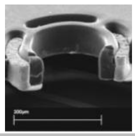
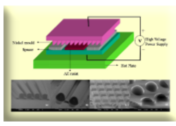
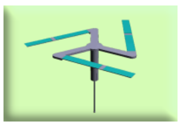
- Subtractive.
- Volume shaping.
- Additive.

An alternative approach is to classify processes in terms of their typical operating environment:

- Temperature.
- Pressure.
- Specialist gas compositions.
- In-vacuo.
- Specialist liquid requirements.

A non-exhaustive diagram is provided above to illustrate the principle. It will be seen that *integratable* processes naturally cluster where no specialised environment is required.

The primary processes in outline

Technology	Brief description	Application example	
Etching & lithography	Subtractive patterning processes – where material is removed to leave a wanted pattern - are the basis for systems on semiconductor, conventional printed circuit boards, and also the creation of tooling for many other manufacturing processes.	Optical mask generator *femto-st*	
Printing & nanoimprinting	Printing processes build up material in prescribed shapes upon a surface and range from the deposition of material via screen printing and other printing methods, through to nanoimprinting, which at the nano- scale may combine stamping with material deposition to create fine surface features.	Fully automatic screen printer *Heriot-Watt University*	
Micromachining, forming & handling	Micromachining, forming and handling group together those essentially “mechanical” processes that may be applied to Smart Systems manufacture. Machining and forming can often be applied, with skill, to the manufacture of models, prototypes and small batches.	Powder blasting *Heriot-Watt University*	
Microjoining & bonding	Processes to provide permanent bonds between parts at the micro-scale include: welding, compression, laser, thermo-sonic, ultrasonic, radio frequency; brazing and soldering; adhesives; anodic bonding; and many more.	Cavity with electrodes for micro alignment of optical fibres *Heriot-Watt University*	
Moulding & micromoulding	Injection moulding, transfer moulding, overmoulding and vacuum moulding all have there place in the formation of: thermoplastic and thermoset parts; resin and filled resin parts; glass parts; and ceramic parts	Moulded & micromoulded syringe system *Brunel University*	
Deposition & coating	A very broad field, encompassing sputtering, electro deposition, spraying, plasma deposition, and many more. Coating technologies can provide a surprisingly broad catalogue of functions to provide “smart surfaces”, or selective protection for sensors to avoid damage while allowing them to operate.	Joule effect evaporation for thermo-fused materials *femto-st*	
Encapsulation	The purpose of encapsulation is to define the product, and to protect the product and the user, but still allow it to work. In many respects encapsulation resembles coatings in its functionality, the main difference being that it provides its own structural integrity and does not rely upon a supporting structure	Buccal Dose, a system for the oral application of drugs *HSG-IMIT*	
Direct manufacturing & Rapid prototyping	Direct manufacturing and Rapid prototyping differ from typical mass-manufacture processes in that they are typically software driven, with no physical tooling. 3D printing and stereolithography, are two example processes, but others are emerging	Electrostatic induced formation *Heriot-Watt University*	
Test & inspection	Smart Systems, with their integrated structures and composite materials, pose tough questions in Test & inspection. These questions spread further, to encompass the validation of tooling, the calibration and control of manufacturing processes, and the characterisation of multi-parameter sensors and actuators.	Micro CMM probe *UK National Physical Laboratory*	
Repair & recycling	Regulations for the collection, recycling and disposal of technological products at the end of their useful life are well established in the EU, especially in terms of electronic goods and cars. On the other hand, disposal has, overtaken repair and routine maintenance in the field,	Automatic Disassembly using Smart Materials *Brunel University*	

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Etching & lithography

Overview

Subtractive patterning processes – where material is removed to leave a wanted pattern - are the basis for systems on semiconductor, conventional printed circuit boards, and also the creation of tooling for many other manufacturing processes.

"Photolithography" is primarily associated with semiconductor manufacture, where feature size is continually reducing, leading to major pushes in both technology and the cost of lithography equipment.

Chemical etching, associated mainly with printed circuit boards but also with the creation of mechanical items, also follows a trend to smaller feature sizes.

Other processes, such as laser ablation, plasma etching, electron beam and ion beam technologies can achieve "maskless" patterning by directly "writing" the necessary shapes.

Importance for Smart Systems Integration

- Fundamental to semiconductor technology
- Multitude of approaches for other materials, mass manufacture, and also "batch of one"

Hurdles to be overcome

- Outside semiconductor manufacture, Smart Systems production has lower requirements for ultimately small geometries, but perhaps tighter requirements for repeatable tolerances.
- Semiconductor and Printed Circuit production processes are geared to mass manufacture. Smart Systems may also fit this volume, but also may be of much smaller production runs, or customised, in which case more flexible, affordable and accessible processes are needed.
- Etching and lithography processes tend to take place within specialised gaseous or liquid environments, particular to the process and the material being processed. The processing of integrated multimaterial Smart Systems presents research challenges..

Centres of excellence

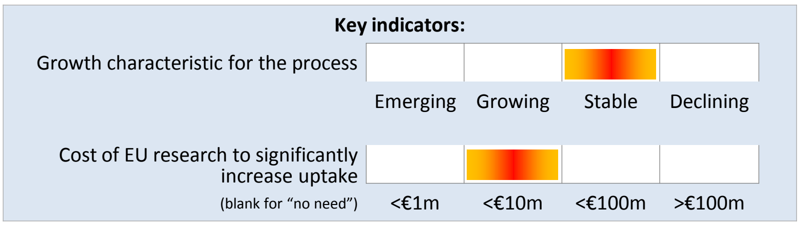
Semiconductor lithography development is notably in the Netherlands and Japan.

Other subtractive processes are developed in many centres, globally.

Prospects

Low cost, yet repeatable processes for dimensions greater than those used in semiconductors will be ramping up by 2020+

Table-top systems and self-contained systems are needed to work perhaps without a clean room, for SMEs and low volume requirements.



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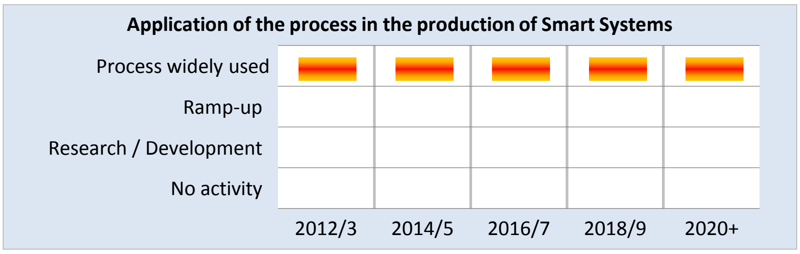
Impact

Product benefits: More repeatable Smart Sensors with lower calibration costs, at reduced manufacturing cost .

There are global opportunities for sales of machines globally, especially for sensors, actuators and fluidics.



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Printing & nanoimprinting

Overview

Printing processes build up material in prescribed shapes upon a surface and range from the deposition of material via screen printing and other printing methods, through to nanoimprinting, which at the nano- scale may combine stamping with material deposition to create fine surface features.

"Jetting" of liquid or molten materials is a non-contact method for pattern generation, and has the useful ability to be applied to contoured surfaces.

The "3D printing" of bulk materials does not necessarily depend upon a surface to build upon, and is treated in this chapter as "Direct Manufacturing & Rapid Prototyping"

Importance for Smart Systems Integration

- Printing allows the build-up of differing materials, creating integrated functionality.
- Printing processes tend to work within free air or benign gases, and are therefore potentially suitable for simultaneous multi-material integration.
- Printing can occur at high speed over large areas, and is well suited to "reel-to-reel" manufacture.

Hurdles to be overcome

- The large-area production of multi-material combinational sensors at low cost.
- Multi-scale combinations of nanoimprinting and printing processes to act simultaneously or sequentially on production lines.

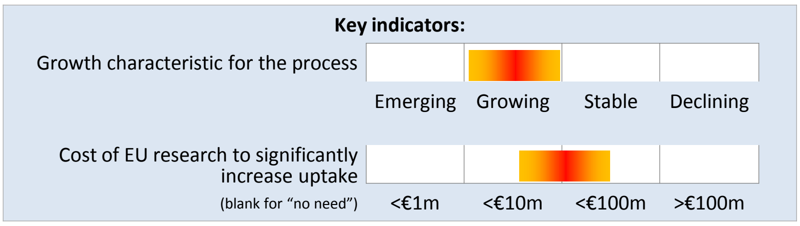
Centres of excellence

VTT, IMEC, several industrial companies such as NIL, Microdrop, Zeiss, KIT (Germany)

Prospects

Printed Smart Systems promise new display technologies, flexible, non-planar substrates, and advances in Human Machine Interfaces.

The process is ideally suited for the mass manufacture of low cost items, and for the integration of Smart functionality into everyday objects.



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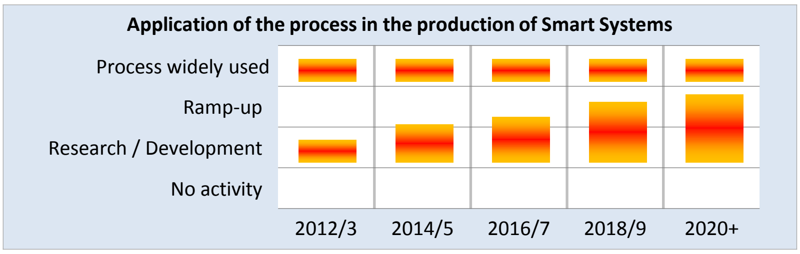
Impact

Printing, depositing materials only where required, is a low-loss process.

Currently there is wide use of printing technologies to form passive interconnects. Development will create printed active components, sensors and actuators.



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Micromachining, forming & handling

Overview

Micromachining, forming and handling group together those essentially “mechanical” processes that may be applied to Smart Systems manufacture.

The purely mechanical processes of micromilling, drilling and powder jetting are joined in this grouping by thermo-mechanical processes such as laser machining and ablation, Focused Ion Beam and spark erosion.

Forming by stamping and folding may also include self-forming and shape-memory techniques, while mechanical handling can include micro-grippers, conveyors, vibratory feeders and air flotation.

Importance for Smart Systems Integration

- Machining and forming can often be applied, with skill, to the manufacture of models, prototypes and small batches.
- Parts handling and alignment applies (1) to the integration of Smart Systems themselves and (2) to the integration of Smart Systems into any further product and system hierarchy.

Hurdles to be overcome

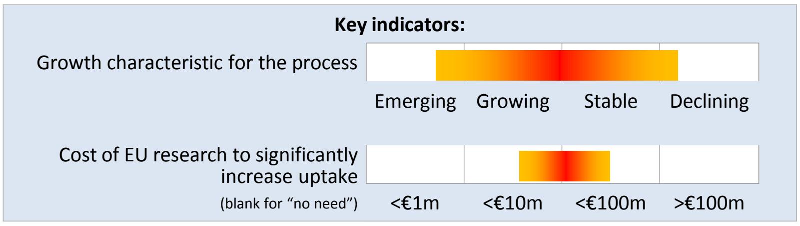
- Very dependent upon highly skilled people for a small fraction of their time.
- Some Smart Systems require multiple functions from single elements. This constrains process selection and process combination.
- Developments need to drive towards 3D
- Some new materials very difficult to form and machine.

Centres of excellence

Cranfield University, Cambridge University, VTT, CEA-Leti, SPTS (Oxford), Percipio Robotics

Prospects

Micromachining, forming and handling together represent a wide range of processes, which are individually at different stages in their life cycles.



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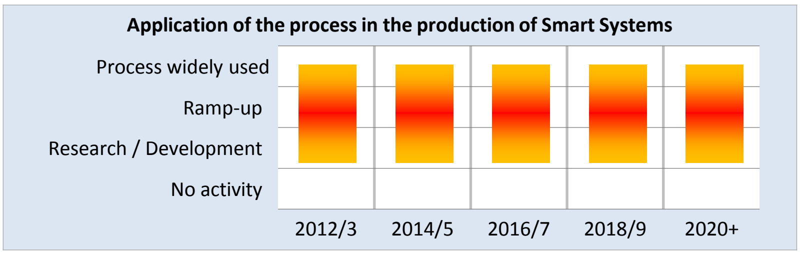
Impact

Although the breadth of processes themselves may require only incremental development, their successful application to highly integrated multimaterial Smart Systems will depend upon the continuous availability of high skill levels.



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Microjoining & bonding

Overview

Processes to provide permanent bonds between parts at the micro-scale include:

- Welding: resistance, compression, laser, thermo-sonic, ultrasonic, radio frequency.
- Brazing and soldering.
- Adhesives.
- Anodic bonding.

This wide range of processes allows an appropriate selection according to:

- whether the joint is between similar or dissimilar materials.
- whether the bond needs to be mechanically strong.
- whether the joint needs to be conducting or non-conducting for electricity, heat, light, gases or fluids
- whether the joint needs to flex to allow for, as an example, differing temperature expansion.
- whether a degree of hermeticity is required.

Importance for Smart Systems Integration

- Joining and bonding are fundamental for the integration of components to form subsystems and systems.
- The selection of appropriate joining techniques, or combinations of techniques, can provide a buffer between otherwise incompatible components.

Hurdles to be overcome

- Smart System Integration, which spans electronics, fluidics, bio- and many other disciplines, requires an extension of the range of well-characterised bonding processes.
- At the micro- and nano- scales, interfaces become a greater proportion of the bonding structure. Dust, electrostatics and other forces come into play. Scientific approaches to the modelling of performance and reliability are needed.

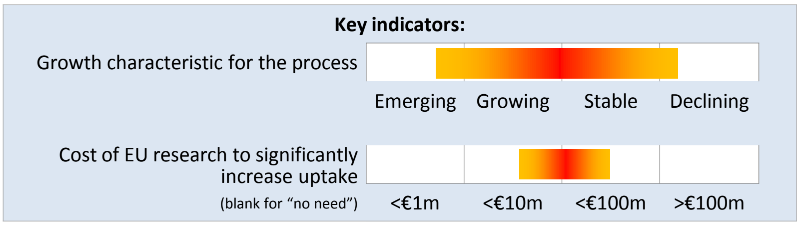
Centres of excellence

Fraunhofer Chemnitz. Zeiss (wafer bonding). EVG (Austria), AML (UK), AMKOR, ASE, RESCOLL

Prospects

Microjoining and bonding together represent a wide range of processes, which are individually at different stages in their life cycles.

A great deal of work is needed to assess how differing techniques may be combined to optimise the performance and reliability of integrated systems.



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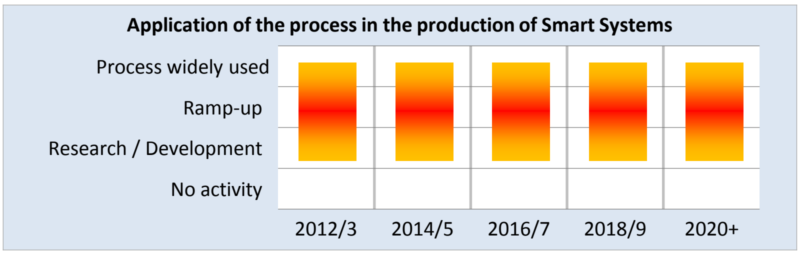
Impact

Although the breadth of processes themselves may require only incremental R&D, their combination could result in valuable highly competitive IPR that is difficult to replicate or reverse engineer.



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Moulding & micromoulding

Overview

Injection moulding, transfer moulding, overmoulding and vacuum moulding all have their place in the formation of:

- Thermoplastic and thermoset parts.
- Resin and filled resin parts.
- Glass parts.
- Ceramic parts.
- Whether a degree of hermeticity is required.

At the micro-scale, moulding processes can create features at the nano- scale.

Importance for Smart Systems Integration

Mouldable materials bring the capability to:

- Form 3D shapes.
- Create tubes and channels for fluids, light guides and microwave propagation.
- Create translucent windows and lenses.
- Envelop or interface to non-mouldable parts.
- Cheaply replicate precision parts

Hurdles to be overcome

- Embedding instrumentation into the tooling to increase accuracy and repeatability.
- Specialist polymers and powders formulated for use at the micro- scale, and as sensors and actuators.
- Biocompatible materials for medical devices.
- Techniques for moulding inserts at the micro- scale
- Mould making at the micro- scale.
- Parts handling at the micro- scale.
- The development of specialist materials in very small quantities, economically.
- High recyclability of materials, as wasted “sprue” material may be high in proportion to the material used in the finished part.
- How to prototype with precision.

Centres of excellence

KIT (Germany). Battenfeld (Germany), KEIKU (Netherlands), Morgan Ceramics (UK), Pôle Européen de Plasturgie, FEMTO-ST

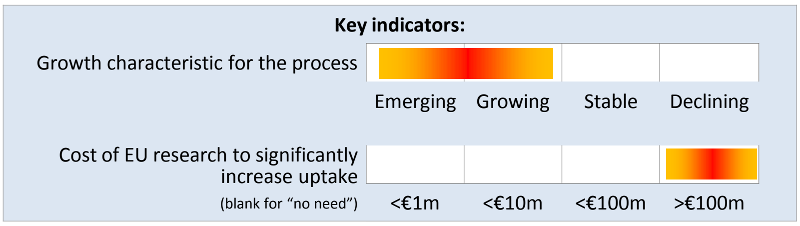
Prospects

Today’s moulding machines, developed from conventional production machines, are typically massive in scale compared to micromoulded parts.

There are strong opportunities for the ground-up development of machines specifically aligned to the needs of Smart Systems integration.

Impact

Moulding and micromoulding present opportunities for breakthroughs in the high volume production of truly integrated Smart Systems as products.



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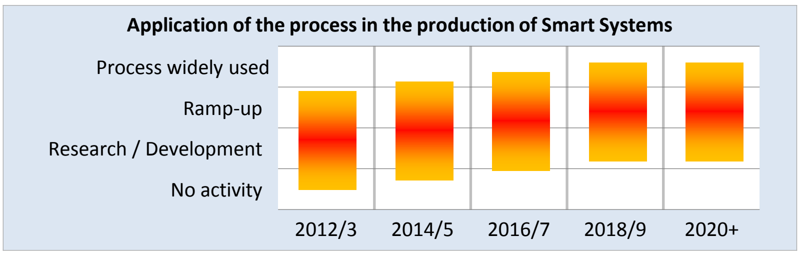

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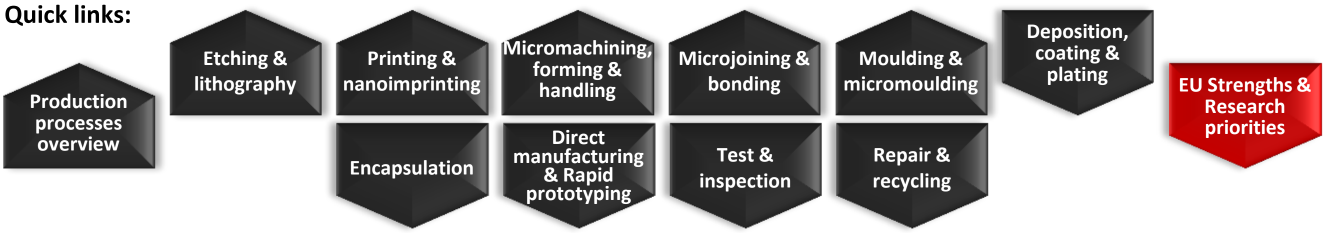


Deposition, coating & plating

Overview

A very broad field, encompassing sputtering, electro deposition, spraying, plasma deposition, and many more, with functionalities including:

- Decorative and tactile properties.
- Protection against mechanical, chemical, biological or radiant (heat, light etc) damage. Note that this protection can apply to products, users, or both.
- Passive functional coatings as precursors to the formation of features through, for instance, etching.
- Passive functional coatings to provide screening or reflective properties, catalysis, antiseptic and hydrodynamic / aerodynamic properties.
- Permeable coatings that allow the selective ingress of powders, liquids and gasses whilst protecting sensors against the operating environment.
- Sensitive coatings that record the history of a product, for example temperature excursions, gas and liquid immersion, impact events.
- Active coatings to provide sensing capabilities and self-healing protection.

Importance for Smart Systems Integration

Coating technologies can combine many of the foregoing perhaps surprisingly broad catalogue of functions to provide "smart surfaces", or selective protection for sensors to avoid damage while allowing them to operate.

Hurdles to be overcome

- The development of hierarchies of compatible processes, coating materials and substrate materials
- The development of active "Smart Surfaces"
- Characterisation and test methods for advanced coatings
- Lifetime prediction of functional surfaces

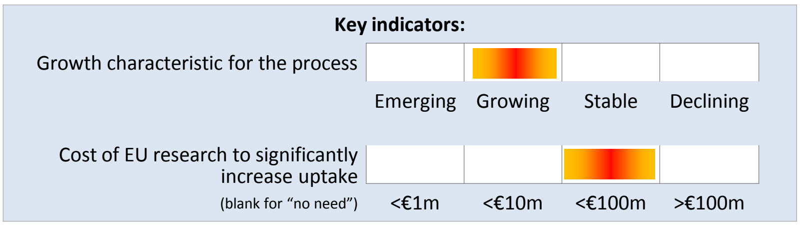
Centres of excellence

CSEM, EMPA, AKZO-Nobel, University of West of Scotland (Thin film centre), University of Edinburgh, Alsace University , LERMPS-UTBM, Mäder group

Prospects

Touch-sensitive displays are now familiar, but the future will surely see surfaces that interact in other ways with product users and the environment.

Reproducible coating techniques are fundamental enablers for Smart Sensors and their integration into textiles, and the built environment.



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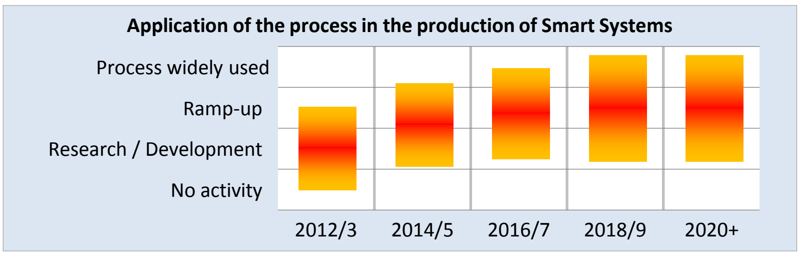
Impact

Advanced coating developments could lead to valuable IPR and competitive advantage, as the processes and materials are difficult to "reverse engineer".



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Encapsulation

Overview

The purpose of encapsulation is to define the product, and to protect the product and the user, but still allow it to work.

In many respects encapsulation resembles coatings in its functionality, but with two major differences:

- Encapsulation provides its own structural integrity and does not rely upon a supporting structure.
- Encapsulation can, through machining or moulding, integrate structural features such as fixings and aids to the handling and operation of the product.

The primary functions of encapsulation include:

- Protection against mechanical, chemical, biological or radiant (heat, light etc) damage. Note that this protection can apply to products, users, or both.
- The containment of gases, liquids and powders.
- Permeable encapsulation that allows the selective ingress of powders, liquids and gasses whilst protecting sensors against the operating environment.

Importance for Smart Systems Integration

Integrated Smart Systems need to survive the environment that they operate in, from the benign environments inhabited by humans through to the extremes of the automotive drive train, aerospace and implanted medical devices.

At the same time they need to interface with these environments, so encapsulation may play dual protective and transmissive roles.

Hurdles to be overcome

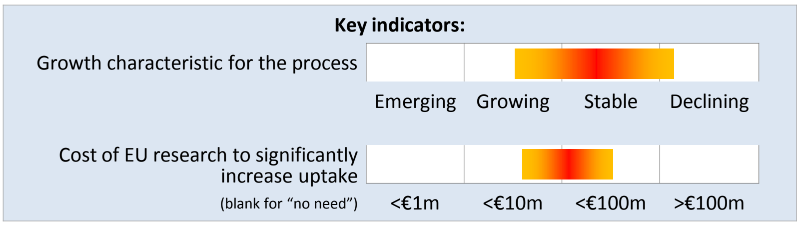
- Functionally adaptive encapsulation – reacting to type of use and by position in the product life cycle
- Reductions in the amount of encapsulation without compromising functionality
- Links to coating and nano- technologies

Centres of excellence

AMKOR, ASE

Prospects

Whilst there are significant prospects for new forms of encapsulation, notably in the biomedical field, it should not be forgotten that product miniaturisation and the drive to reduce the consumption of raw materials is leading to a decline in demand for some traditional encapsulants, and the processes that apply them.



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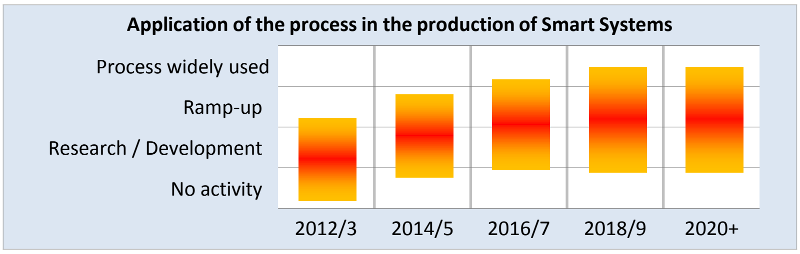
Impact

As for coating, developments in encapsulation could lead to valuable IPR and competitive advantage, as the processes and materials are difficult to "reverse engineer".



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Direct manufacturing & Rapid prototyping

Overview

Direct manufacturing and Rapid prototyping differ from typical mass-manufacture processes in that they are typically software driven, with no physical tooling. 3D printing and stereolithography, are two example processes, but others are emerging, including one novel process where materials are sculpted under the influence of electric fields.

- Direct manufacturing (“tool-free manufacturing”) allows for “batch of one” product customisation
- Rapid prototyping allows for the production of (life-size, upscaled or downscaled) models to illustrate and trial/review one, some or all aspects of a product that is subsequently to be manufactured using more economical series manufacturing processes

The processes used may typically be slow, but the timescales and up-front costs are low, which can be over-riding considerations when just a few items are required or, as in the case of prototyping, multiple aspects of a product need to be examined, perhaps iteratively, as part of the design cycle.

Importance for Smart Systems Integration

Smart Systems, with their facility for customisation, are a good fit for Direct manufacturing, and the need to understand the user interface and ergonomics of Smart Systems makes Rapid prototyping an important element of their product design and development cycle.

Hurdles to be overcome

- Current processes can produce parts, but not systems. Research is needed into processes that can do both, using multiple materials.
- There is a need to understand and predict the difference in performance between prototypes and final products manufactured in volume.

Centres of excellence

Centre of Innovative Manufacturing in Additive Manufacturing (Nottingham & Loughborough Universities, UK), University of Louisville (USA), University of Texas, El Paso (UTEP), 3D-Systems, Stratysys, Optomec, Renishaw, Cresilas, Vienna University of Technology

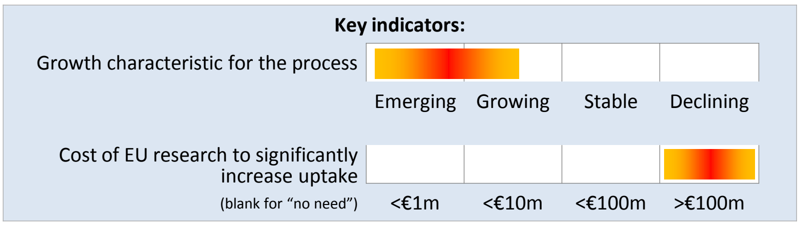
Prospects

In practice, Direct manufacturing might only differ from Rapid prototyping solely by how one manages the process.

Uptake may be driven by the “localisation” of manufacture in domains such as medical prosthetics, where in-theatre or by-theatre production may be very desirable.

Impact

Personal customisation of otherwise standard products and accessories, and the “desk-top” manufacture of downloaded designs may result in profound changes in the economy of certain product sectors.



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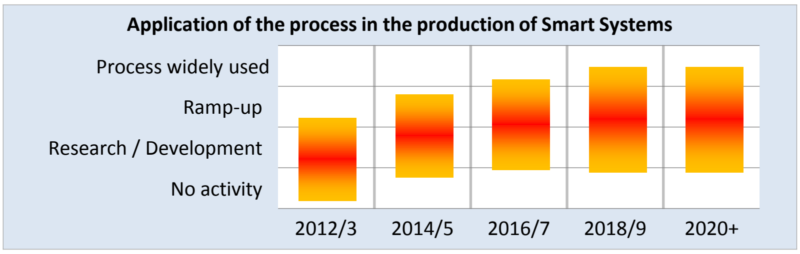

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Test & inspection

Overview

Smart Systems, with their integrated structures and composite materials, pose tough questions in Test & inspection.

These questions spread further, to encompass the validation of tooling, the calibration and control of manufacturing processes, and the characterisation of multi-parameter sensors and actuators.

The advanced expertise of the test laboratory has not yet made it to the production environment, but it will be needed there. Smart, adaptive Test & inspection must be integrated into every phase of design and manufacture.

Importance for Smart Systems Integration

The EU position on complex Smart Systems could be eroded by poor yields and reliability, and the shear breadth of technologies and scale – nano, micro, meso, macro, opto , bio, fluidic etc – is daunting.

But the very "smartness" of these systems may bring self testing (& repairing) parts and subsystems.

Hurdles to be overcome

- The development of in-process measurement and feedback techniques suitable for 3D multi-material structures and the manufacturing tools that act upon them.
- The qualification of highly-integrated products by non-intrusive methods at production line speeds.
- The examination and interpretation of the environmental and reliability performance of complex systems – possibly by self-testing.
- Understanding the relationship between accelerated testing and in-service reliability, and how this can be predicted at the design stage.
- Exploiting experience from early users in space, medicine and security.

Centres of excellence

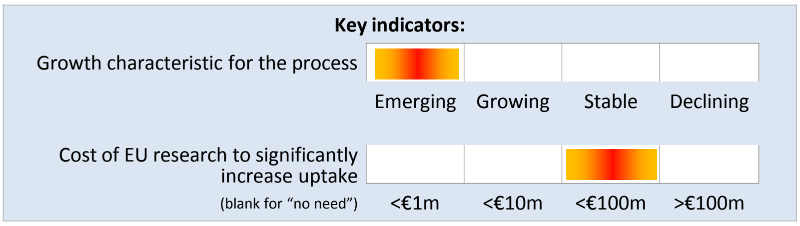
National Physical Laboratory (UK) Renishaw (UK). EADS (EU), University of Lancaster (UK)

Some centres, eg Fraunhofer ENAS, are part of a chain

NIST (US)

Prospects

Although the testing and characterisation of parts, even at nano- and micro-dimensions, is well developed and deployed, there are significant needs and opportunities for non-intrusive on-line methods for examining complex systems, and self-test-and-calibration built into the Smart Systems themselves.

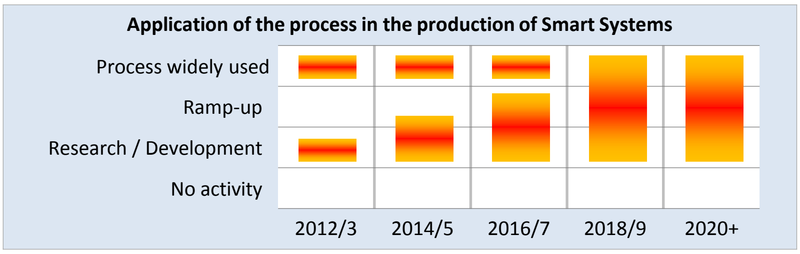


The indicators above and below are shaded to reflect uncertainty

Impact

There is a global market for the in-line inspection of complex parts.

EU companies have already proved their ability to prosper in the global Test & inspection sector, which is growing with the rapid expansion of manufacturing everywhere.



Quick links:

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Moulding & micromoulding
Deposition, coating & plating
EU Strengths & Research priorities
Encapsulation
Direct manufacturing & Rapid prototyping
Test & inspection
Repair & recycling

Repair & recycling

Overview

Regulations for the collection, recycling and disposal of technological products at the end of their useful life are well established in the EU, especially in terms of electronic goods and cars.

On the other hand, disposal has, for typically reasons of economics, overtaken repair and even routine maintenance in the field, but repair/rework in manufacture is still unfortunately relatively commonplace.

Dwindling resources of certain scarce materials has encouraged re-use and “urban mining”

Importance for Smart Systems Integration

Without action, the tide of smart waste, containing rare materials, will continue to rise. To counter this, Smart Systems might self-identify faults, and the materials used to aid repair or deconstruction.

Alternatively, some Smart Systems may evolve into “Self-Consuming Systems” that can adapt, transform or evolve their function once their current role is completed, or intentionally digest themselves to become benign waste at their end-of-life.

Hurdles to be overcome

- Grow the deconstruction sector, financed from recovered materials.
- The development of new process chains to deconstruct high technology products.
- The detection of contaminated hazardous returned products.
- Design for reuse or deconstruction.
- Bio-degradable subsystems, eg displays.
- A review of the state of recovery and disposal in high technology products and materials.

Centres of excellence

Brunel University (UK): Automatic Disassembly using Smart Materials

City University of Hong Kong (ECA Centre)

Prospects

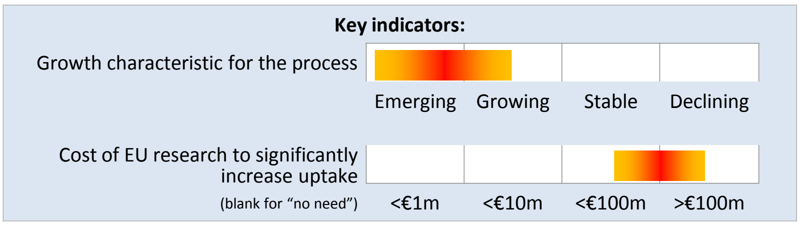
A strong environmental culture in the EU, aligned with regulation, will continue to press developments in Recycling and Re-use.

Repair - possibly confined to reworking initial manufacture, must be allied to smart developments concerning in-line Test & inspection.

Impact

Urban mining and new process chains to deconstruct or re-use high technology products represent high growth business opportunities.

It will be, however, a long journey.



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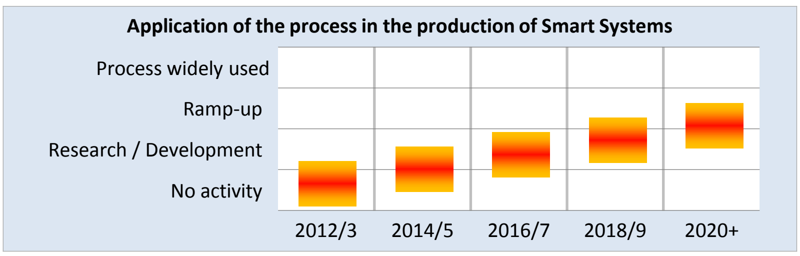

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Production Processes for Smart Systems: European position

Sub-sector	Strengths	Weaknesses	Opportunities	Threats
Processes overall	• A potentially good community of companies and clusters with Smart systems readiness	• Conservatism in investing in untried techniques	• Advanced processes enable new products • Combining of advanced processes	• Low cost manufacturing
Etching & lithography	• Global players • Technology players	• Supply chain dependent upon mass semiconductor and PCB fabricators remaining in the EU	• Develop or custom Smart Systems and precision parts orientated capability • Table-top systems and self-contained systems are needed to work perhaps without a clean room	
Printing & nanoimprinting	• New generations of equipment being developed by EU companies and RTOs	• High cost of some equipment precludes its use for research and low volume production	• Low cost, low throughput equipment • Invest in upscaling for production	• Nanoimprinting perceived only as a niche application for R&D
Micromachining, forming & handling	• Good networks nationally, but not EU-wide • Expert small companies	• State of art difficult to assess, due to trade secrets • Access to fabrication capabilities vary from nation to nation	• Fresh approaches combined with capturing old skills	• Skills migrate as processes migrate
Microjoining & bonding	• Mainly mature techniques	• Not recognised as an "expert" subject, as companies "do it anyway"	• Self healing bonds • Apply knowledge from specialised safety-critical industries to the fabrication of Smart systems	• Integrated Smart Systems could disintegrate unexpectedly and set back acceptance and growth
Moulding & micromoulding	• LIGA process for tooling	• Only a handful of specialist companies and researchers	• Develop appropriately-scaled micromoulding machines • Automated and de-skilled self-improving operation, including tool changes • Smart, instrumented, tooling • Fully recyclable materials	• Regulation slows advances for medical devices • Low cost moulding goes to Asia to co-locate with other assembly operations
Deposition, coating & plating	• Global EU players	• Invisible, fragmented • Regulation needs to be based upon safety to users, this blocks development	• Develop effective trade secret coatings, difficult to reverse engineer • Health monitoring and defect indicating coatings and encapsulants	• Big players relocate, supply chain withers
Encapsulation	• History in high reliability, precision products • Good knowledge in implantable medical devices	• Specialist research centred in Institutes, not companies	• Encapsulation adaptive over life and function • Reduce encapsulation without compromising functionality	• Restriction through regulatory standards lagging behind development
Direct manufacturing & Rapid prototyping	• Lot of research interest • Good materials science • Strong design-led industry • Strong demand • Engineering-led • Key patents held	• EU not using internet service provision possibilities as well as other regions, so capabilities are hidden	• Make capability more visible and approachable • Capture EU market quickly • Compensate for caution in conventional EU manufacture	• 600 on-line 3D print service providers in China • Technology seen as mainly for prototyping , not as a flexible production tool
Test & inspection	• Strong security inspection industry • Quality sensitive	• Lack of enforcement of statutory standards	• Global market for on-line inspection of complex parts	• EU Smart Systems could be compromised by poor yields and reliability
Repair & recycling	• Strong environmental culture	• Finding user pull	• Develop new processes to deconstruct high -tech products, with profit from recovered materials • Detection of hazardous returned products	• RoW imposes standards earlier • Organised crime

Production Processes for Smart Systems: Research priorities

Sub-sector	Priority actions	Longer term actions
Overall	•Encourage product-led access to advanced processes, and combinations of advanced processes	•Generate data fusion techniques for harvesting of data into information, and information into insight.
Etching & lithography	•Blue sky new ideas needed in this domain, particularly to engineer Smart Systems with high repeatability •more flexible, affordable and accessible processes, possibly table-top systems and self-contained systems are needed to work perhaps without a clean room •The processing of integrated multimaterial Smart Systems presents research challenges as etching and lithography processes tend to take place within specialised gaseous or liquid environments, particular to the process and the material being processed.	
Printing & nanoimprinting	•The large-area production of multi-material combinational sensors at low cost •Multi-scale combinations of nanoimprinting and printing processes to act simultaneously or sequentially on production lines	
Micromachining, forming & handling	•Some Smart Systems require multiple functions from single elements. This constrains process selection and process combination •Developments need to drive towards 3D •Some new materials very difficult to form and machine	•Micromanipulation, and the modeling of micromanipulation •Development of CAD models easily translatable from the computer to machine tools (computationally intensive step). “Beyond FEM”.
Microjoining & bonding	•Well characterised surface chemistries •Scientific approach to interfaces •Modelling of joining processes •Predict aging of bonds in use conditions	
Moulding & micromoulding	•Develop Processes in scale with the finished component •Microscale moulding at lower cost. •Design optimisation	
Deposition, coating & plating	•Research and develop hierarchies of compatible processes and materials. •Active “Smart Surfaces”	
Encapsulation	•Demonstrator projects for “Application Specific Encapsulation” in several use environments	
Direct manufacturing & Rapid prototyping	•Product exemplar projects in companies •Make Direct Manufacture and Rapid Prototyping capabilities more visible, and easy to work with •Development of additive manufacturing for more capable production systems with increased energy efficiency and performance compared to traditional manufacturing processes.	•Methods to assess performance variation from prototype production to mass production •Multifunctional material products •Open architecture rapid prototyping manufacturing equipment.
Test & inspection	•Self testing (& repairing) parts and subsystems •Convergence from early users in space, medicine and security	•Physics-based simulation
Repair & recycling	•Design for reuse or deconstruction •Bio-degradable eg displays •A coordination action to review the state of recovery and disposal in high technology products and materials	

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