EPoSS
European Technology Platform
on Smart Systems Integration

2017

Strategic Research Agenda

OF THE EUROPEAN TECHNOLOGY PLATFORM
ON SMART SYSTEMS INTEGRATION

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PREFACE

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PREFACE

DOTT. CARMELO PAPA

CEO and Director General, STMicroelectronics Italy

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In providing a range of novel functionalities, smart systems have become a driving force behind almost all product innovations, and smart-enabled solutions can be found in almost every application field: transportation, health, manufacturing, the Internet of things (IoT), energy, natural resources and security.

With its long history of ingenuity, Europe is a world leader in smart systems and their integration. This leadership is crucial for the competitiveness of companies and entire industry sectors. However, keeping up with the pace of technological development on a global scale requires a great increase in investment in smart systems research, not least to withstand the growing competition from other regions and to counterbalance the losses experienced by other key technology sectors. On that basis, a group of stakeholders decided in early 2005 that the different perspectives along the smart systems value chain should be unified into what would be called the European Technology Platform on Smart Systems Integration – in short, EPoSS was born.

This is of utmost importance as smart systems integration has evolved into a decisive concept for solving some of the key challenges for humankind.

Since 2007, experts from European industry and academia involved in EPoSS have successfully translated and condensed their expertise in regularly published Strategic Research Agendas (SRAs). These documents capture ongoing developments and provide decision-makers across Europe with important perspective and insights on future research priorities in this fast-paced technology field.

By considering the objectives, strategy and impact of smart systems integration for seven application fields, and deriving related system integration needs and pointing to research priorities in four transversal fields of enabling technologies, 10 years after its first publication EPoSS members have now updated this document for the fourth time. The experts have developed roadmaps, set milestones and defined actions to be taken for each of these fields over the next 15 years. This document therefore constitutes an important basis for joint activities in the area of SSI, and thus will be essential for shaping the future landscape of smart systems research.

This is of utmost importance as smart systems integration has evolved into a decisive concept for solving some of the key challenges for humankind. Also, over the last 10 years we have witnessed a shift in the focus of smart systems integration, with the latest transition being towards a greater emphasis on sensors and microelectronics in an era of comprehensive automation – ie, strong interaction with energy and data networks, and decreasing human interference.

Although smart systems integration has been on the radar for quite a while, it could not be a more timely topic for 2017! I would like to express my sincerest thanks to everybody who contributed to this document and I like to invite all readers to follow the journey of smart systems integration for years to come.

2

INTRODUCTION

2

INTRODUCTION

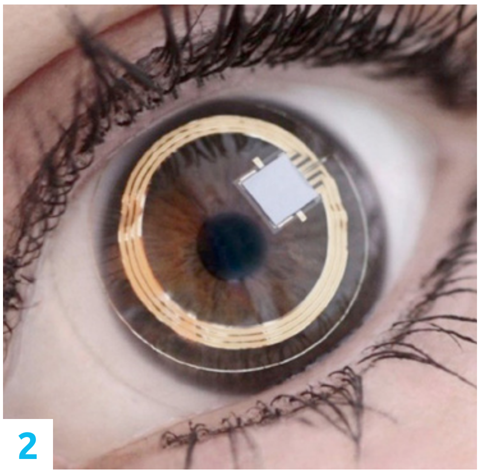
2.1

Smart systems integration

Smart systems combine cognitive functions with sensing, actuation, data communication and energy management in an integrated way. The enabling principles of these functions include nanoelectronics, micro-electromechanics, magnetism, photonics, chemistry and radiation.

Figure 1 shows five examples of smart systems for industrial, medical, automotive and environmental applications.

1



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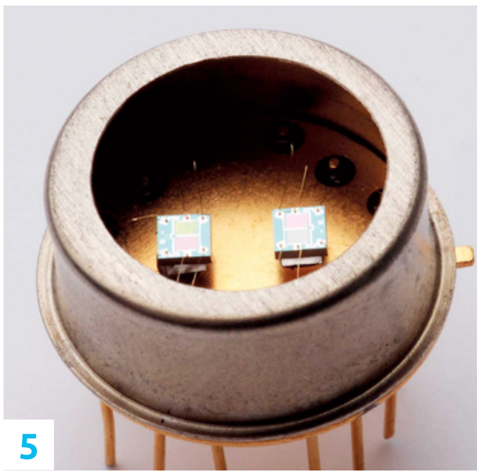


5

1
Smart systems for robots in collaborative environments **(Bosch)**

2
Intraocular pressure measurement device **(Sensimed STM)**

3
Advanced driver Assistance systems **(Bosch)**

4
Minimal invasive cardiac surgery device **(Sorin/LivaNova)**

5
Semiconductor gas sensor **(FhG IPM)**

Figure 1: Examples of smart systems

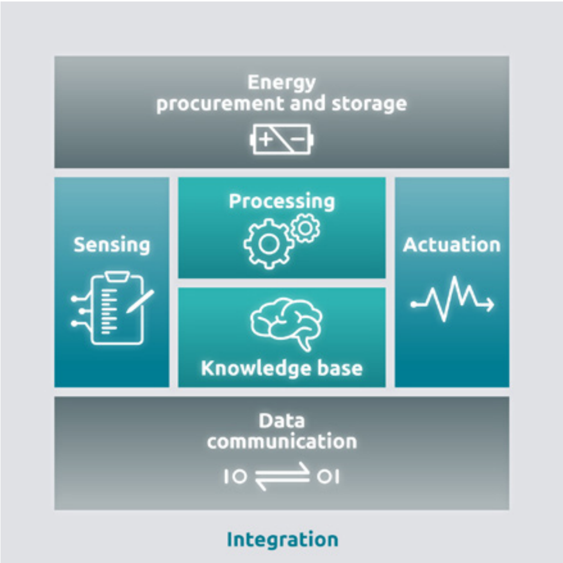


Figure 2: Building blocks of a smart system

What separates a smart system from a system that is purely reactive is the knowledge base, which ranges from a set of parameters for a feedback loop to embedded databases and algorithms. It is a necessary condition for the smartness of a system to provide safe and reliable autonomous operation under all relevant circumstances. The building blocks of a smart system are shown in Figure 2.

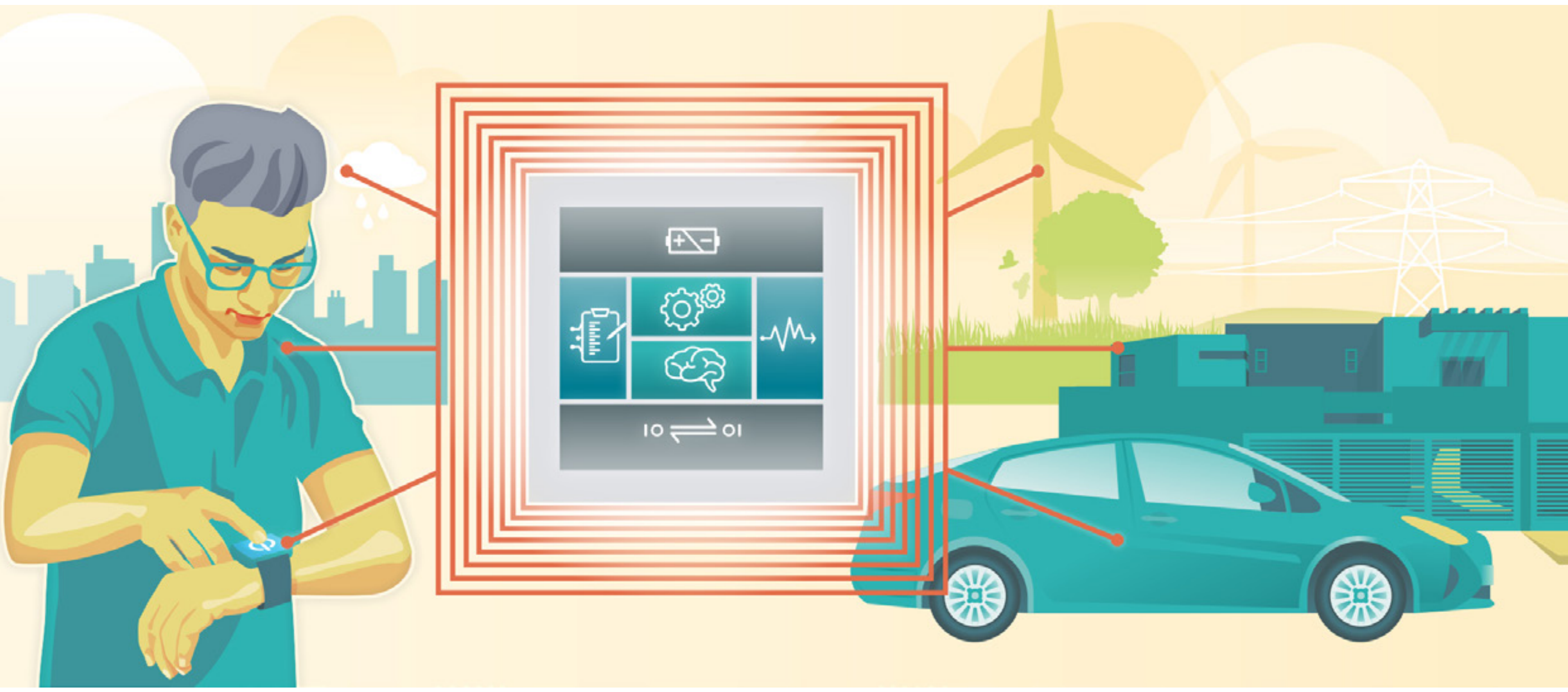


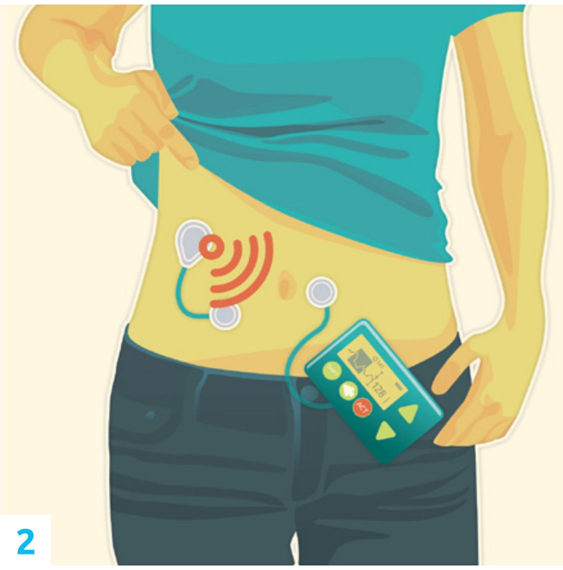
Figure 3: Interaction of smart systems with their environment

Smart systems are often integrated with the (natural, built and social) environment, networks for power and data, other smart systems and the human (see Figure 3). It is a sufficient (or extrinsic) condition for the smartness of a system to provide (and use) cognitive support to (and from) its surroundings.

System functionalities determine advancements in “smartness” (see Figure 4). These can be expressed in terms of:

1

FIRST-GENERATION smart systems that integrate sensing and/or actuation, as well as signal processing, to enable actions (e.g., the gyro mouse)



2

SECOND-GENERATION smart systems built on multi-functional perception, and which are predictive and adaptive (e.g., continuous glucose monitoring)

3

THIRD-GENERATION smart systems that perform human-like perception and actions, and which generate energy (e.g., fully automated driving)

Figure 4: First-, second- and third-generation smart systems

2.2

Structure of the chapters

This SRA covers both transversal topics and application fields as shown in Figure 5.

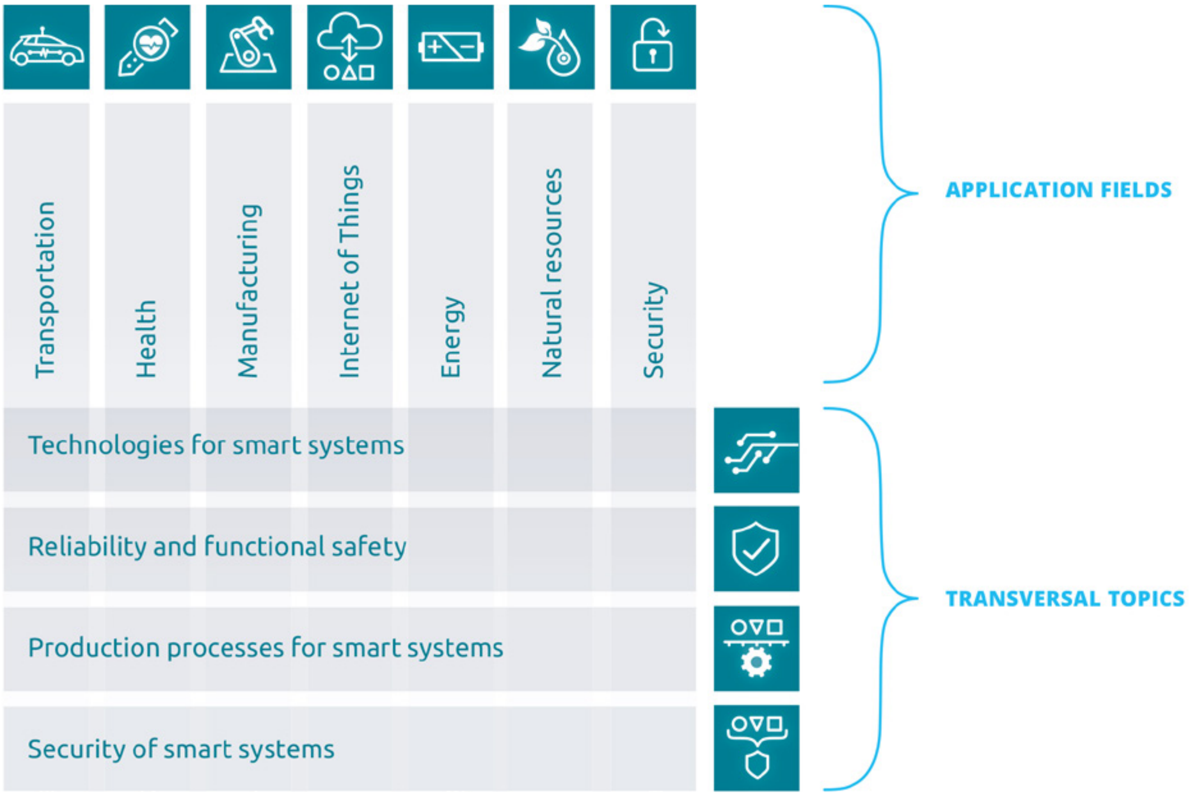


Figure 5: Structure of this SRA

Chapter 3

APPLICATION FIELD

For the application fields, each sub-chapter follows the same structure.

OBJECTIVES After a short general definition of the application field, links are made to the societal challenges this application field affects, the roles of SSI to meet such challenges are explained, and the objectives of SSI regarding developments in the application field are described.

STRATEGY The state of the art of smart systems development in the application field is analysed in detail, and the research, development and innovation (R&D&I) challenges regarding the objectives are stated.

IMPACT The socioeconomic impact of the application field and the share of SSI therein are stated, and the links to challenges for the R&D&I (chapter strategy) and societal challenges and objectives (chapter objectives) are made.

ROADMAP The actions in terms of R&D&I for smart systems needed to achieve the objectives for the timescale up to 2030 are expressed in terms of a roadmap.

Chapter 4

TRANSVERSAL TOPICS

For the transversal topics, the chapters are similarly structured.

OBJECTIVES After a short definition of each transversal topic, the enabling role of the transversal topic within SSI is described, with links to the application fields being made to show the transversality.

STRATEGY The state of the art of the transversal topic enabling the smart systems development is described, and the R&D&I challenges towards the objectives are stated.

IMPACT Challenges for the R&D&I (chapter strategy) and objectives (chapter objectives) are linked, with an explanation of how meeting the R&D&I challenges will impact developments in SSI.

ROADMAP The actions in terms of R&D&I in enabling technologies for smart systems needed to achieve the objectives on the timescale up to 2030 are expressed in terms of a roadmap.

2.3 Roadmaps

The roadmaps (see Figure 6) are structured along milestones that show the progress for the years 2020, 2025 and 2030. They are linked to defined objectives and strategies within the application fields or transversal domains, and refer to developments that have reached high technology readiness levels (TRLs) at 2020, 2025 and 2030. The actions indicate *what* needs to be done and *when* in terms of SSI (for application fields) or enabling technologies (for transversal topics) to achieve the milestones. They are grouped in action fields. Timescales of R&D, demonstration, and production and market introduction are also distinguished.

Figure 6: Structure of the roadmaps

3

APPLICATION FIELDS

3

APPLICATION FIELDS

3.1
Transport and mobility

3.1.1 OBJECTIVES

Despite the economic challenges faced by industry, Europe remains a major producer of motor vehicles of all types. It is worthwhile mentioning that the European Union (EU) is the world's largest investor in automotive industry R&D. In fact, EU companies in the car and parts sector have continued to increase their investment in R&D, with the automotive sector being the EU's number one investor in R&D, with €41.5 billion invested annually. Hence, maintaining this leading edge will be essential for the competitiveness of the EU automotive sector in global terms, and also in light of sharp discontinuities that are likely to occur due to:

- The introduction of new CO_2 and emission regulations (including worldwide light-duty test cycle (WLTP)/real driving emissions (RDEs))
- The ever-increasing role of electronics in vehicle innovation
- The development of new applications and business models
- The societal challenges ahead, such as interconnected society, urbanisation, ageing, social inclusion and environmental factors

Within this context, smart (heterogeneous) systems integration will play a fundamental role in enabling smart (green and integrated) mobility.[1]

The aim of this section is to ensure the development of advanced and cost-effective SSI solutions, from R&D to technology transfer into products, with regard to the following action fields.

OBJECTIVE 1 Clean, efficient and electrified propulsion

Europe is the cradle of the internal combustion engine (ICE), and must leverage its know-how to develop further this technology. Although there have been problems with emission levels from the technology and resultant changes in industrial product strategies, there are still opportunities for efficiency improvement and emissions reduction due to the massive adoption of advanced electronic controls systems and e-actuators. However, this approach should be complemented increasingly by the progressive electrification of powertrains and energy storage systems through more optimised and affordable solutions. Important synergies and technological transfers are envisaged, from x-EV architectures and powertrains for cars, buses and trucks to avionics, where there is an emerging demand for e-aircrafts.

OBJECTIVE 2 Advanced driver assistance systems (ADAS), connectivity and automation

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

OBJECTIVE 3 Infrastructure for transport

The transition towards e-mobility requires an adequate level of modern and efficient infrastructure, particularly with respect to charging. Cyber-security through hardware (HW) technology will play a significant role in vehicle-to-everything (V2X) connectivity,[2] but will be particularly essential in over-the-air (OTA) updates where a saving of $45 billion by 2022 is predicted.[3]

OBJECTIVE 4 Smart mobility services

Mobility is one of the key aspects of modern society, and a basic requirement for a strong economy and social well-being. At the same time, urban mobility is facing new challenges. The increasing size of our cities de-

1 *Horizon 2020 Work Programme 2016/2017, "Smart, Green and Integrated Transport".*

2 *ACEA, "Strategy Paper on Connectivity", April 2016.*

3 *IHS Automotive, "The Connected Car", January 2016.*

mands greater road safety, better traffic flow and environmental sustainability. SSI will allow for the optimal utilisation of vehicles for personal mobility and transportation in congested urban areas. In fact, an increase in the effective capacity of the road system(s) – enabling projected future increases in traffic volume (a 38 % increase in passenger traffic and 68 % in freight traffic by 2050, compared to 2005) – is projected, with road capacity expected to grow at a minimal rate.[4]

3.1.2 STRATEGY

The connected society will address the convergence of industrial sectors, products and technologies. Consequently, this roadmap will slightly broaden its horizons towards transportation as a whole, including railway and avionics, while keeping the centre of gravity on the automotive industry since it provides critical mass. Another very important strategic aspect relates to the increasingly frequent and relevant interaction with other domains (e.g., cognitive science, biomedical, IoT) to support the development of new innovative concepts in the automotive industry (e.g., interiors based on thin, organic and large area electronics (TOLAE), human-machine interface (HMI), non-invasive health monitoring, V2X) and other transformational technologies.

The adoption of SSI in transportation has grown over the years due to these state-of-the-art technologies:

- Multi-core processors with embedded non-volatile memory (NVM) in 90/65nm technology node, running up to 300 MHz
- HW encryption mechanisms for data security, integrated into microcontrollers

Integration of different sensing technologies (e.g., radio frequency (RF), antenna, photonic sensors, micro-electromechanical systems (MEMS), smart drivers, piezo and capacitive sensors) into mechatronic systems for active safety and comfort

- Integration of different actuating technologies (e.g., electrovalves, e-motors) into control systems for powertrain (e.g., transmission, exhaust gas, turbo compound, e-drive)
- Integration of different power ratings (e.g., low, medium, high) and different interconnection technologies (e.g., printed circuit board (PCB), direct bonded copper (DBC), interconnection management system (IMS), bus bars) into control systems (e.g., AC/DC, DC/DC converters) for e-mobility applications
- Deterministic and high-speed communication networks
- Advanced imaging systems (e.g., camera, signal passed at danger, SPAD) for fatigue and drowsiness detection
- Flexible electronics for interiors

Consequently, the R&D&I challenges for smart systems integration towards reaching the objectives in transportation stated above will be the following.

STRATEGY 1 Adaptive energy storage systems

It will be key to enhance the development of the next generation of adaptive energy storage systems for e-vehicles. These systems should be able to detect precisely in real time the state of health (SOH) and state of charge (SOC) of the vehicle over the lifespan, thus taking into account ageing effects and reconfiguring the system if there is severe degradation of any of the cells.

STRATEGY 2 New electric drives

This strategy is based on the development of the next generation of electric drives, especially important as the use of advanced e-motors will reduce the dependency on rare earth materials and affordable power electronics. With regard to power electronics, new solutions for much more efficient integration (e.g., control logic, power devices, interconnections, high current/voltage sensors) are required to improve both power density and efficiency. The availability of silicon carbide (SiC) and complementary metal oxide semiconductor (CMOS) gallium nitride (GaN)-based devices will be fundamental to the achievement of such targets.

STRATEGY 3 Technological transfer

Technological transfer from automotive to avionics is envisaged, as this would meet an increasing demand for e-aircrafts. This would mean technology such as powertrain architectures, electric drive technologies and energy storage systems could be transferred into this domain, exploiting the benefits of mass production: affordability, reliability and longer lifespan.

4 *EUCAR, "The Strategic Pillars of Automotive Research & Innovation".*

STRATEGY 4 Developing the fuel cell electric vehicle market

There are great prospects for the fuel cell electric vehicle (FCEV) market over the next 20-25 years, and leading car manufacturers are expected to launch several models. There is a need for improved fuel cell systems both on-board and on-road (charging), especially as most FCEVs are classified as zero-emission vehicles.

STRATEGY 5 Advanced driver assistance systems

A crucial strategy will be ADAS based on cost-effective heterogeneous integration to assist the widespread adoption of active safety systems on each vehicle segment. In addition, a central element will be the development of "hypervisor" systems based on the next generation of massively parallel micro-controllers for the implementation of sensor fusion techniques and advanced control algorithms for vehicle control.[5]

STRATEGY 6 Ergonomics

The increasingly effective interaction between medical experts and automotive engineers will lead to the development of new solutions in the area of ergonomics. In particular, the generation of sensors that offer non-invasive detection of physiological parameters (e.g., glucose, heart rhythm, breath rate, O_2 concentration) will provide a basis for the unprecedented – and much more accurate – analysis of a driver's health status (such as drowsiness and fatigue). Such information will feed into the automated driving systems and result in any necessary safety manoeuvres, as well as in-vehicle systems for superior comfort level (e.g., active ergonomics).

STRATEGY 7 Fast communication networks

The introduction of high-speed deterministic communication networks will provide seamless interconnection of smart systems in the vehicle, as well as the fundamentals for the implementation of fail-operational software architectures and deep-learning tools.

STRATEGY 8 Technology infrastructure

The technological transition towards e-mobility requires an adequate level of supporting infrastructure, particularly with respect to charging. Both wired and wireless technologies must be developed further to provide the most affordable solutions to customers.

STRATEGY 9 Cyber-security

The development of cyber-secure, in-vehicle networks based on smart drivers embedding hardware security module (HSM) will provide an effective solution that covers the widest range of car segments. Most importantly, cyber-security technology is essential for the OTA approach, as both SW and maps (e.g., infotainment, engine/transmission calibration) will be updated directly from the vehicle manufacturers.

STRATEGY 10 V2X technology

Smart mobility services will establish more seamless, economic and sustainable mobility in the smart cities of the future. Hence, advanced V2X technology that is combined with automated driving technology will be fundamental to providing the optimal utilisation of new vehicle concepts for personal mobility and transportation in congested urban areas. These services will also be the basis for radically new mobility models – including robot taxis, self-driving shuttles and cooperative fleets of drones for last-mile delivery.

STRATEGY 11 Combining electrification and automation

Vehicle manufacturers and automotive suppliers are increasingly exploring the potential benefits and synergies of combining automotive electrification, automation and connectivity to future mobility, as the integration of these technologies may simplify the electric and electronic architecture of the car, and lead of vehicle concepts that meet user demands in an ideal way.[6]

5 "User Perspectives On Autonomous Driving – A Use-case-Driven Study in Germany", Geographisches Institut, Humboldt-Universität zu Berlin, 2016.

6 Gereon Meyer and Susan Shaheen, Disrupting Mobility – Impacts of Sharing Economy and Innovative Transportation on Cities. Springer, Cham 2017.

3.1.3 IMPACT

The automotive industry provides a very important impact at the EU level in both economic and societal terms, and requires further effort in R&D&I to improve its competitiveness: the proposed roadmaps have been elaborated accordingly.[7]

In fact, according to the European Automobile Manufacturers Association, the EU produced 18.4 million motor vehicles in 2015 nearly a quarter of the world's total, and the car industry as a whole supports 12.1 million jobs across Europe. Of these, 2.3 million are involved directly in the manufacture of Europe's cars, vans, buses and trucks, representing nearly 10.4 % of total manufacturing employment in the EU. The car industry is also a global player and a major exporter, with a € 95.1 billion trade surplus. Motor vehicles accounted for € 396 billion in tax contribution in the EU in 2015.

Connected and automated driving will revolutionise individual mobility within the next decade, offering new possibilities for safe, efficient, comfortable and environmentally friendly transport, as well as creating new areas of business with new players impacting the existing automotive business models.[8]

There is no doubt that the growing connectivity of motor vehicles, together with their progressive automation is giving drivers more time to carry out activities other than driving when they behind the wheel, creating potential additional market volume for internet-based services almost equal to the current market. Today, approximately 2.4 billion people spend an average of 20 minutes online each day (800 million hours in total). That same amount of time is spent in the car (800 million cars, with an average driving time per day of one hour).[9]

The EU's core values apply as much to the physical world as the digital one. Hence, the EU's vision in the cyber-security domain has been outlined in a comprehensive proposal: it clarifies roles and responsibilities, and sets out the actions required based on strong and effective protection and promotion of citizens' rights to make the EU's online environment the safest in the world.[10]

Proposed activity about the non-invasive detection of physiological parameters is highly relevant, both at the social and the political level, having been inspired by EU Directive 2014/85/EU, where new risk factors for motor vehicle accidents have been identified and included, and which is subject to mandatory implementation by all member states from December 31, 2015.[11] The roadmap relies on the effective interaction with transversal topics, such as "reliability and functional safety", "technologies for SSI" and "production processes for smart systems".

It is important to note that car manufacturers recalled a record 51.26 million vehicles in the US in 2015, continuing a historic surge in such companies facing an unprecedented government crackdown on safety lapses. According to the National Highway Traffic Safety Administration, this topped the 50.99 million vehicles recalled in 2014.[12] These numbers demonstrate clearly the significance of innovative methodologies in the field of design for excellence (DfX) in reliability, testing and manufacturing.

7 IBM Institute for Business Value, "Automotive 2020: Clarity Beyond the Chaos"; Frost & Sullivan, "Fast-forward to 2025: New Mega Trends Transforming the World as We Know It", 2014;Roland Berger, "Automotive Landscape 2025: Opportunities and Challenges Ahead", 2014; Frost & Sullivan, "2015 Automotive Industry Outlook and Strategic Insight", 2014;McKinsey & Co, "The Road to 2020 and Beyond: What's Driving the Global Automotive Industry?", 2015; ACEA, "New Passenger Car Registrations by Alternative Fuel Type in the European Union", Quarter 4, 2015; IHS Automotive, "Global Automotive Outlook – Return to Sustainable Growth in 2016?", January 2016; IHS Automotive, "Upcoming Challenges for West European New Vehicle Demand", January 2016; IHS Automotive, "Hydrogen Fuel-cell Electric Vehicles and Refuelling Infrastructure Market: Now or Never?", January 2016; IHS Automotive, Alternative Propulsion Scenarios: Requirements to Turn an Offer-driven Market into a Demand-driven Market", January 2016; IHS Automotive, "The Future of Europe as Production Location – Evolving to an export hub?", January 2016.

8 Gereon Meyer and Sven Beiker (Eds), Road Vehicle Automation. Springer, Cham 2014.

9 Prime Research, "Connected Mobility and Digital Lifestyle", April, 2015; NVIDIA Strategy Analytics, "Automotive Infotainment & Telematics, Munich 2014;Roland Berger, "Global Automotive Supplier Study: Record Profits vs Increasing Profitability", December 2014.

10 "Cybersecurity Strategy of the European Union: An Open, Safe and Secure Cyberspace - Joint Communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, 2013.

11 "New Standards and Guidelines for Drivers with Obstructive Sleep Apnoea Syndrome – Report of the Obstructive Sleep Apnoea Working Group", EC 2013; Commission Directive 2014/85/EU.

12 Frost & Sullivan, "2015 Automotive Industry Outlook and Strategic Insight", 2014; Baker & Mc Kenzie, "Product Liability and Product Recall Overview: Focus on the EU, Russia, Brazil and Mexico", October 2015; KPMG, "Global Automotive Executive Survey 2015".

3.1.4 ROADMAP

In the following action items evolving from R&D, to demonstration and implementation, into industrial practice, are summarized illustrating selected high-priority topics on the timetable.

ACTIVITY FIELD 1 Clean and efficient propulsion

- Development of smart actuators for the next generation of clean ICEs. Wider operating range through packaging, interconnection technology and next generation of wide-band gap based components
- Development of next generation of adaptive energy storage systems for EV/HEV: improved run time detection of SOH/SOC, keeping into account ageing effects and reconfiguring the system in case of severe degradation of some cells
- Development of the next generation of electric drives, as the combination of advanced e-motors with reduced need for rare earth materials and affordable power electronics. New power electronics featuring improved power density and power efficiency by means of more efficient integration of subsystems. The availability of SiC and CMOS based GaN based devices will be important for the achievement of such a targets while extending the operating range
- Technological transfer from automotive to e-aircrafts, with particular regard to powertrain architectures, electric drives technologies and energy storage systems. Focus on affordable cost, reliability and lifetime
- Development of the next generation of affordable FCEVs with regard to their systems: on-board storage systems and charging systems on road

ACTIVITY FIELD 2 ADAS, connectivity and automation

- Development of a new generation of sensors for the in-vehicle non-invasive detection of physiological parameters (e.g., glucose, hearth rhythm, breath rate, O2 concentration) and much more accurate analysis of the driver's health status (e.g., drowsiness, fatigue). Development of system of systems architectures and interaction with ergonomics systems for superior comfort level (e.g., active ergonomics)
- Development of affordable electrified city cars for urban mobility and transportation (see also Activity field – smart mobility services)
- Next generation of ADAS systems based on cost effective heterogeneous integration of building blocks (i.e. sensing, computing, networking) supporting automated driving on large scale (up to level 4/5)
- Development of "hypervisor" systems based on the next generation of massively parallel micro-controllers for the implementation of sensor fusion techniques and advanced control algorithms for automated vehicle's control (up to level 4/5)

ACTIVITY FIELD 3 Infrastructure for transportation

- Development of the next generation of wired and wireless on road charging technologies providing the most affordable and reliable solutions to the customers
- High-speed deterministic communication network for the efficient interconnection of smart systems in the vehicle and the backbone for the implementation fail operational architectures
- The development of cyber-secure in-vehicle network based on HW solutions to cover the widest range of car's segments. The proposed cyber-security technology will support the over-the-air (OTA) updates of SW and maps (e.g., infotainment, engine/transmission calibration) directly from the OEMs

ACTIVITY FIELD 4 Smart mobility services

- Advanced V2X and automated driving technologies for the optimal utilisation of new vehicles' concepts for personal mobility and transportation in the congested urban areas
- Development of self-learning systems for e-vehicles (e.g., electric drives, energy storage systems) for improved availability in the urban mission and remote maintenance
- Development of cooperative fleet of drones for last-mile delivery
- Development of robot taxi for personal urban mobility

For the roadmap on SSI for transportation and mobility, the following milestones have been identified (see Figure 7):

Milestone 2020

Automated driving and freight

Milestone 2025

Synergies of automation and electrification

Milestone 2030

Converging all modes in transport

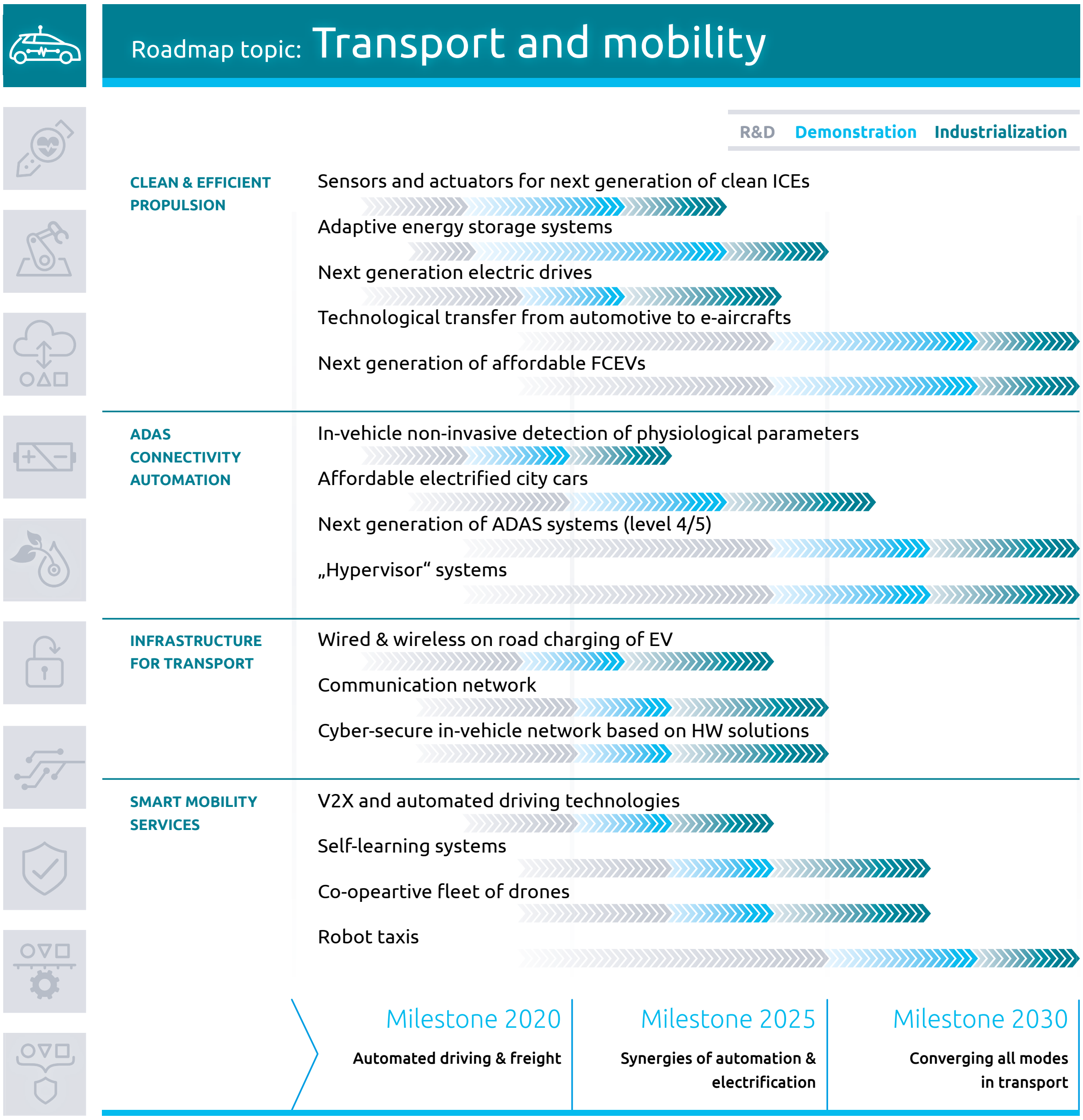


Figure 7: Roadmap for transport and mobility

3.2

Health and well-being

3.2.1 OBJECTIVES

The overall objective of this section is to provide the EPoSS vision for smart systems-based solutions to address European industrial, societal, medical and economic challenges, as well as to satisfy end-user and patient needs.

Innovative technologies in healthcare have long been integrated into devices that treat acute or chronic diseases, and which affect vital prognoses or alter drastically the quality of life of numerous patients. However, tremendous progress in research fields such as bionic, biomedical, bio-sensing, bio-energy harvesting and low-power electronics for communicating securely and extending processing and memory capacities now offer completely new approaches based on artificial intelligence, deep learning and the understanding of biological mechanisms at the origins of diseases that will radically change the way diseases are diagnosed, treated and followed-up. Healthcare is seen increasingly as an integrated and transparent component of everyday life, and future medicine innovations will prevent patients from being excluded, even if temporarily, from a "normal" life.

Well-being contributes hugely to this approach, as it is a crucial ingredient for the prevention of disease, thus creating a necessary bridge between everyday life and healthcare. Well-being is highly supported by technological approaches with a high degree of penetration to individual end-users.

Healthcare systems face a huge challenge in providing the same level of care, in an appropriate, efficient and cost-effective way, to a burgeoning population. By 2030, the world population will have risen by 1.3 billion, the middle class by 3 billion; due to ageing, the world's population in the age bracket 65+ is projected to increase by 436 million people and the urban population by 1.5 billion, who will require increased access to healthcare facilities and services.

Last, but not least, the way healthcare is provided is changing substantially as medical interventions are no longer confined to hospitals, clinics or medical offices, but are occurring anywhere in people's life, especially in their home. Ambulatory, "point-of-care" and "home care" are terms that will gain in significance in the future.

This trend of "decentralised" healthcare will not only have an impact on how medicine reaches the patient, but will require a redefinition of the role and positioning of healthcare providers. Smart systems have the potential to provide suitable solutions, both to support the rising importance of individuum-centred delivery of healthcare and to smarten existing healthcare providers to cope with paradigm shifts in medicine and ensure a continuum of care.

To face these challenges, the smart systems community has identified three main objectives to improving well-being and healthcare with smart systems solutions, thereby addressing the current issues and trends in healthcare – i.e. more prevention, prediction, personalisation, participation and increased productivity of smart system-based medical devices:

- Responding to unmet clinical need by applying a "smart filter", both in an incremental and in a disruptive way
- Enabling "decentralised" healthcare provision
- Supporting harmonious, trust-based relationships within the healthcare continuum

OBJECTIVE 1 Responding to unmet clinical need by applying a "smart filter"

Smart medical systems are, and will be, adopted by physicians as they represent an effective and safe solution to the particular clinical need to diagnose, treat, cure or follow-up diseases or injuries. From their point of view, solutions are often disconnected from technology since they are experts in medicine and not necessarily in microelectronics or microfluidics. Different technologies can achieve the same functionalities and thus respond to particular needs. Smart systems have the potential to bring (partially or entirely) the best available response to some of the current unmet clinical needs aligned with economical and industrial constraints. For its 2016 Strategic Research and Innovation Agenda,[13] the European Technology Platform for Nanomedicine (ETPN) collated a list of unmet clinical requirements in medical applications with the major incidence on the European population. On this list, which was based on a survey of clinicians across Europe, smart system-based solutions could have a major impact by filtering these needs.

Smart systems have the ability to advance healthcare solutions, both in an incremental but also a disruptive way.

- Incremental approach: Enhancing existing products and processes by providing faster and more reliable solutions for the pharma, biotech and medtech industries – e.g., using drug screenings for small and large molecules, organ on a chip, smart surgical tools
- Disruptive approach: Developing new approaches to improve radically the way diseases are diagnosed, treated and taken care of at home. Examples of disruptive solutions can be found in diagnostic medical devices and therapeutical medical devices (implantable or wearable), as well as in after-care at home (implantable, wearable, ambient-assisted). They also open up new approaches in combining applications – e.g., theranostics, smart medical devices, augmented surgical tools

OBJECTIVE 2 Enabling "decentralised" healthcare provision

Smart systems are already part of everyday life and benefit from high acceptance rates within the population. To realise a transition toward delocalised healthcare provision, smart systems can therefore play an important role, as they enable:

- Complex diagnostics with combinational sensing abilities, monitoring and treatments on a wearable, in vivo, portable or home basis
- Connected and personalised solutions
- The safety and reliability of smart medical solutions, which can range from wearable diagnostic health patches and electrocardiograms to smart contact lenses that can help diabetes patients monitor their glucose levels

Existing healthcare infrastructures (hospitals, clinics, GPs) will have to adapt to offer patients on-site, high-quality and cutting-edge medical services using safer, more efficient, specialised, accurate, solutions.

Smart systems have the potential to optimise medical services and tools by reducing risk and introducing cost-effective, innovative solutions for assisting and supporting doctors with:

- Decision-making based on accurate, quick, reliable, multi-modal in vitro and in vivo diagnostic tools and the access to worldwide resources and references
- New approaches using targeted or alternative deliveries of therapy by enhancing or replacing human organs by artificial smart system-based organs (e.g., cochlea for deaf patients, retinas for sight-impaired patients, pancreas for diabetes patients, left ventricle assisted devices or heart pumps for congestive heart failure patients)
- Their medical interventions using enhanced surgical tools
- The recovery and rehabilitation processes of patients
- Their remote monitoring of observed patients at home

OBJECTIVE 3 Supporting harmonious, trust-based relationships within the healthcare continuum

While biology and chemistry can interfere directly with biological mechanisms at the atomic or molecular level and treat diseases at their origination, smart systems can link the micro and macro environments and thereby support the integration of health in society and everyday life (e.g., well-being, prevention, diagnostics, support treatment, after-care, access to information). The support includes:

- Between technology providers and healthcare providers (hospitals, insurances, physicians) in terms of procurement and cost-effectiveness of smart systems
- Between healthcare providers and patients (m- and e-health)
- At home, implementing efficient prevention by smart appliances supporting consumers in healthy nutrition and healthy behaviour

Smart systems consider medicine and well-being not only in technological terms but also to highlight the crucial role of non-technological issues, such as ethics, regulation, privacy, accessibility and equality, which are key to increasing the acceptance and adoption of innovation in healthcare. Furthermore, smart medical devices have the potential to reduce the social gap between healthy and disabled people, thereby contributing to social equality, notwithstanding that access to these technologies is not guaranteed.

13 *"Nanomedicine Strategic Research & Innovation Agenda 2016–2030: Creating Junctions for Healthcare" (available at www.etp-nanomedicine.eu/public/press-documents/publications/etpn-publications/Nanomedicine%20SRIA%202016-2030.pdf).*

In a decentralised healthcare ecosystem, healthcare infrastructures (hospitals, clinics, medical practices) will continue to play a central role since they are nodes that ensure the continuous link of information between individual patients and healthcare professionals. Similar to the food industry with its "cold chain", the "information chain" in healthcare should in no case be interrupted as it may endanger patients and loosen the trust relationship patients have with their physicians. Smart systems contribute to the robustness of this information chain by providing the chain links for information generation (sensing, acquiring, analysing and validating data), for safe storage and propagation, as well as for its correct decryption and understanding.

3.2.2 STRATEGY

The strategy for SSI in health and well-being can be expressed in four main ways: "smarter than smart"; "smart solutions for continuum of care"; "reaching individuals"; and "smart by design".

STRATEGY 1 Smarter than smart

This term refers to less electrical power consumption and more of the following: reliability and safety; integration; miniaturisation; hybridisation; processing and memory; energy autonomy; connectivity; functionalities; cognition; autonomy; deep-learning capabilities; intelligence; intuitive interfaces; and design for increased productivity.

STRATEGY 2 Smart solutions for continuum of care

Multi- and cross-cutting key enabling technologies (KETs) approaches will provide a full solution to clinical, societal, economical and industrial needs. The RO-cKETs study published in 2014 offers a roadmap[14] of the potential areas of industrial interest relevant for cross-cutting KETs in the health and healthcare domains. It highlights the cross-fertilisation of micro and nano-electronics, nanotechnologies, advanced materials, advanced manufacturing systems, photonics and biotechnology to produce innovative devices and systems for targeted diagnostics and personalised medicine, more efficient and less invasive drugs and therapies, as well as smart systems and robots for healthcare services. The crucial role of SSI is to provide a "package" for the combination of KETs. In addition, linking with EU initiatives in healthcare (e.g., Innovative Medicines Initiative, IMI, Emerging and Strategic Technologies for Healthcare, ESTHER,[15] European Institute of Innovation & Technology (EIT) Health, Human Brain Project, EUREKA) to promote integrated solutions for healthcare and to link up with neighbouring areas (such as IoT, big data, cloud computing, artificial intelligence, robotics) is essential.

STRATEGY 3 Reaching individuals

The ability to reach individuals will be facilitated by promoting and supporting the personalisation of well-being and healthcare. Solving non-technological challenges is essential to unlock the potential of smart systems for health. Validation that considers multiple criteria (such as technical, medical, industrial, regulatory, standard, societal and economical aspects) will de-risk innovation. Multi-level education and training is required – for patients, technologists on medical requirements/ medical staff on potential of technologies, public authorities, research and industry staff. This should not be limited to the healthcare systems, but go far beyond to reach out directly to individuals at home and work. Smart appliances will enable the implementation of preventive strategy with regard to daily nutrition, exercise and the way we work (or will work in the future). The societal challenges of fighting obesity and type 2 diabetes[16] can only be addressed by changing our nutritional habits, and smart systems are an excellent way of achieving this in a positive way by making healthy decisions easier.

STRATEGY 4 Smart by design

Collaborative design is based on the involvement of multiple stakeholders, including healthcare providers, healthcare payers, public authorities, researchers, industrials and patients, integration of societal, medical, economical objectives during the design phase. It will increase productivity without endangering safety, ethical and sustainability aspects or having an environmental impact.

14 *"Ro-cKETs – Roadmap for Cross-cutting KETs Activities in Horizon 2020" (available at http://ec.europa.eu/growth/industry/key-enabling-technologies/eu-actions/ro-ckets/downloads/cross-cutting-kets-roadmap_en.pdf).*

15 *"ESTHER: Proposal for an Industry Driven Initiative on Emerging and Strategic Technologies for Healthcare (available at www.enatrans.eu/public/events/german-french-colloquium-innovation-from-bench-to-bedside/esther-proposal-for-an-industry-driven-initiative).*

16 *WHO, "The Challenge of Obesity in the WHO European Region and the Strategies for Response" (available at http://www.euro.who.int/__data/assets/pdf_file/0010/74746/E90711.pdf).*

3.2.3 IMPACT

The ambition is to provide SSI-based solutions that impact stakeholders across the entire health continuum. The stakeholders are individual patients and society in general, healthcare providers, payers, procurers and regulators, industry and the economy as a whole, as well as researchers. Particular impact is expected on small- and medium-sized enterprises (SMEs) and start-ups to maintain, and even increase, the momentum for European smart system-based innovations in health and well-being to be market-ready. For each category of stakeholders, the main ambitions and impact are stated below.

- What can smart systems developers expect from the healthy living sector? Well-being as an (unregulated) field trial for innovation in healthcare is a meeting place for consumer products (electronics, appliance, sport, food and nutrition), and represents a growing future market. It is estimated to be worth €3.000 billion (in comparison, world global healthcare expenditure is currently estimated to be €6.000 billion (€1.000 billion in EU member states), covering different sub-sectors such as healthy eating/nutrition/weight loss (€510 billion), fitness and mind/body (€400 billion), beauty and anti-ageing (€900 billion), preventative/personalised health (€390 billion), complementary/alternative medicine (€160 billion), workplace well-being (€36 billion) and well-being lifestyle real estate (€90 billion).[17] SSI developers will create new market opportunities for European large industry and SMEs. This potential will help maintain and extend the leadership of European Industry.
- What can the European healthcare industry expect from SSI? For industry, SSI is an innovation facilitator and technology enabler that leads to greater productivity, higher security and safety, more reliability and, last but not least, end-user satisfaction.
- What can healthcare providers expect from smart systems? SSI will enable solutions to respond to current unmet clinical needs and unlock new clinical applications.
  - Increased effectiveness will be enabled by early, precise, fast, individualised diagnostic results through more personalised and accurate approaches for treatment based on smart data and decision-support tools that use personal and big data to reduce risks for the patients. Improved training programmes will lead to better-trained professionals.
  - Greater efficiency will be achieved by discharging medical staff from time- and resource-consuming tasks with little medical relevance so that key personnel can refocus on core processes for the benefit of patients. For instance, this is particularly relevant in emergency departments that are regularly congested with patients waiting for clinical data and to be treated medically. Having immediate access to the data recorded by wearables or implants will facilitate the work of emergency staff and contribute to smoothing and optimising acute care. Avoiding risky and cost-intensive trial-and-error approaches through improved predictability on treatment values and increasing patient compliance and acceptability through the wider user of smart systems-based solutions will not only increase efficiency and quality of life for patients, but also contribute to cost-reduction through shorter hospital stays and more ambulatory care.
  - Better integration of healthcare into society can be realised with the help of smart systems by re-humanising the relationship patients have with healthcare professionals and medical service providers, as well as by supporting the building of trust based on having facts and data that are intelligible for all. In addition, smart systems have the potential to prolong the healthcare impact after intervention and hospitalisation in the patient's everyday life (telemedicine, online monitoring, homecare), notably by developing the interoperability of devices and data.
- What can healthcare payers (insurance companies, national authorities) expect from smart systems? SSI will increase patient compliance and reduce costs. It will also provide a leaner approach to healthcare provision.
- What can patients expect from smart systems? SSI will offer devices that facilitate patient compliance and acceptability, improve quality of life, shorten hospital stays and enable a speedier return to "normal life". Also, safer and more secure access to healthcare information, more personalised prevention, diagnoses and treatment will be facilitated. SSI will also reduce the risk of further complications that could result from hospital treatment.
- What can European society expect from smart systems? SSI is key for: creating a European ecosystem around digital healthcare; more efficient use of money spent on healthcare; and reducing side-effects, recalls, complications, re-hospitalisation and medical errors. SSI will improve the quality of life and the productivity of the labour force.

17 *Global Wellness Institute, "Global Spa & Wellness Economy Monitor 2014".*

3.2.4 ROADMAP

To achieve the objective of improving well-being and healthcare through smart systems solutions, further efforts in the design, development, testing, industrialising and marketing of innovative products should be prioritised. Healthcare and well-being represent a continuum and should be considered as such when addressing R&D topics.

The roadmap shown in Figure 8 reflects the actions lines to be addressed in the next 15 years by R&D programmes to realise this continuum of health(care). The roadmap is oriented along five major axes, each aiming to close the gap between the above vision and strategy for SSI and current mega-trends in healthcare. Therefore, the actions lines are viewed as completing the "P4 medicine" approach[18] by introducing the "palliation" P. Each of the five action fields in this roadmap is detailed with the contribution of smart systems to the individual topics, and examples of smart systems-based products to respond to societal challenges in health and well-being, along with the relevant intrinsic characteristics of smart systems that bring the "smartness".

ACTIVITY FIELD 1 Prevention

Effective prevention relies on the increasing convergence of healthcare and well-being on both a technological and non-technological level. Smart systems will enable this convergence and respond to current societal needs as they contribute to:

- Delaying/avoiding appearance of diseases
- Strengthening the body to overcome diseases, developing physical and mental conditions
- Setting environmental, societal and individual conditions for healthy living
- Increasing (self) awareness, compliance and acceptability
- Screening, detecting, tracking and neutralising potential sources of disease or injury
- Increasing the quality of life
- Avoiding the costs and patient suffering linked to re-hospitalisation, complications, medical errors and device failures
- Economic sustainability through new business models for well-being and healthcare
- Improved nutritional behaviour, supporting appliances for personalised nutrition

In this regard, the following three key actions should be considered for the development of smart systems:

- Continuous smart monitoring of medical parameters (quantified by the individual) due to the availability of smart tools to acquire, manage, analyse and store smart (big) data with medical relevance. Such tools should be reliable, safe, intuitive, light, wearable or implantable, autonomous and clinically proven.
- Continuous monitoring of the environment due to the availability of tools that can screen for infectious outbreaks and track pathogens. The focus should be on the convergence of large area monitoring using smart drones and satellite data, but also a network of individual point-of-care devices to prevent larger dissemination. The current geo-political situation highlights the importance of such measures to contain infectious outbreaks and prevent major incidents.
- Adapted interoperable networks and infrastructures to manage, multiplex, analyse and value (big) data generated and support decision-making on a macro level. Such infrastructures should be able to generate smart relevant alerts based on the correlation of data from a huge amount of different and disparate sources.

ACTIVITY FIELD 2 Prediction

Anticipating major events and (re)acting before symptoms and impairments appear is key to increasing quality of life and reducing costs linked to intensive interventions. Advanced smart systems are by their very nature cognitive systems whose predictive abilities allow a smooth transition from prevention to prediction. Relying on reliable facts and smart medical data, they provide early detection as well as early, pre-symptomatic diagnosis of disorders, which is especially relevant for diseases such as diabetes, obesity, atherosclerosis, cardiovascular conditions, cancer, arthritis and neurological or endocrine disorders. Smart systems can provide fast, accurate and high-capacity diagnosis tools at the point of care and in dedicated locations (medical labs, hospitals, clinics).

Future R&D priorities for the enhanced prediction of events and diseases include:

- Smart diagnostics and prediction of disease evolution – these in vitro diagnostic (IVD), wearable or implantable devices should be able to predict the apparition and evolution of diseases to trigger or adjust therapeutic measures
- The prediction of complications or device failures

18 *Leroy Hood, "Systems Biology and P4 Medicine: Past, Present, and Future", Rambam Maimonides Med J., 2013 April, 4(2): e0012.*

ACTIVITY FIELD 3 Precision/personalisation

Achieving truly personalised (individual) medicine will remain a challenge even after 2030, not necessarily because of the lack of individual data gained from smart diagnostics tools or genome sequencing for instance, but due to the difficulty in adapting therapies to individuals with tailored prosthetics or a unique combination of active ingredients. Nonetheless, smart systems can contribute to reaching key milestones (stratified medicine, precision medicine) along the path toward personalised medicine, and thereby support and enhance the personalisation of therapeutic approaches (drugs, neuromodulation, optical, magnetic, acoustic, mechanical or electrical therapy, regenerative medicine, minimal invasive surgery, (micro)robotical surgery) as well as the decision-making processes (for patients, doctors) with the objective to enhance the therapeutic efficacy for distinct groups of patients and to optimise resources.

In this regard, three main development axes will contribute to a more precise, personalised medicine:

- Monitoring of therapy efficacy and medical compliance (including of adverse effects) with real-time, multi-parameter, in-vivo smart medical devices
- Responding to unmet clinical need with incremental approaches, including the enhancement of therapy delivery, more efficient tissue engineering and the development of smart surgery (minimally invasive, remote, image- or sensor-guided, (micro) robotic using enhanced surgical tools with motion and force feedback)
- Supporting faster and environmental friendly therapy discovery with, for instance, smart simulation tools enabling design and testing, reconstructed/in-silico organs, reducing animal use in trials

ACTIVITY FIELD 4 Palliation

Palliation is probably the most likely area in which smart systems can provide breakthrough benefits for patients and offer economic value. In this area, palliation should be mainly understood as the substitution of body parts or organs to relieve patients from distress or to alleviate the effects of serious events. Relying on their ability to adapt in real time to evolving environmental conditions, smart systems can restore partial or complete biological or biomechanical functions of the body and thereby mitigate impairments during and after treatment of disease or injury, as well as tackle the lack of donor organs (heart, lung) or prolong preservation time of explanted donor organs before surgery. In addition, smart systems enable new therapeutic and theranostic-based approaches to fight disease.

With the increasing proximity of smart systems to the human body, the expectations – and also the requirements – for such systems increase. Therefore, the R&D priorities are to improve the "smartness" level of systems.

- Enhanced first-level smart systems: Focus will be on the clinical validation of systems combining real-time sensing and actuation to offer translatable smart theranostics tools, whether wearable or implantable. In addition to medical fields such as cardiology (smart pacemakers) or diabetes (smart insulin management), neurology could benefit greatly from such systems (e.g., sensors for monitoring neuro-communication between brain, nerves and organs, actuators for preventing or treating disease by interfering with the neuro-communication between brain, nerves and organs).
- Increased adaptability of second-level smart systems: This involves the development of new therapeutic approaches based on complex multifunctional perception (neuro-stimulation, deep brain stimulation, companion diagnostics). There is also self-learning prosthetics or implants with multiple senses and pattern recognition, as well as connection with the environment to anticipate external factors and increasing biocompatibility for better adaptation to the human body and its biological and biomechanical processes (soft robots/smart exoskeletons).
- Toward the third level of smart medical systems: This is the development of smart systems with human-like perception and behaviour, full interfacing with the body, high cognitive functionalities, and deep-learning adaptive and intelligent wearable or implanted devices.

ACTIVITY FIELD 5 Participation and collaboration between healthcare professionals and patients

Smart systems are key to realising the delocalisation of healthcare. Mobile health concepts can only succeed with a high level of engagement by the various stakeholders in the healthcare ecosystem and the compliance of patients. Smart systems can provide the tools for connecting people, interfacing systems (for instance, interface with the IoT), fostering mutual exchanges, increasing collaboration and respond to societal needs for trust, safety, mobility and integration. By addressing non-technological aspects of healthcare such as societal, ethical, regulatory, safety and sustainability issues, smart systems can contribute to de-risking innovation and developing new standards in healthcare. For instance, the widespread adoption of remote monitoring, telemedicine or remote rehabilitation will have a significant impact on increasing accessibility to, and the cost-effectiveness of, healthcare as well as on the reduction of inequalities resulting from health-related disabilities (access to jobs, mobility, etc).

- Smart systems to nurture adoption: Promotion of success cases, best practices, impact analysis, consultations, providing safe access to relevant information, supporting complex and collaborative decision-making processes.
- Smart systems to engage the ecosystem: Addressing non-technological aspects of healthcare, such as societal, ethical, regulatory, safety and sustainability issues.
- Smart systems to interface healthcare, society and technologies: Realising an effective interface with big data, IoT and the development of standards.

For the roadmap on SSI for health and well-being, the following milestones have been identified (see Figure 8):

Milestone 2020

Smartisation

Milestone 2025

Smart continuum

Milestone 2030

Smart healthcare

Figure 8: Roadmap for health and well-being

3.3 Manufacturing/factory automation

3.3.1 OBJECTIVES

There is imminent change coming in the factory and manufacturing domain. A remarkable evolution of the entire manufacturing sector through the introduction of new technological and organisational solutions, in synergy with advanced integration of SSI and information and communications technology (ICT) solutions, is taking place – for example, by the incorporation of smart systems in machines and processes (cyber-physical systems, CPS).[19] These changes seem able to: (i) revert the current trend of shifting production to countries with low labour (and other societal) costs through flexible and cost-effective production; (ii) increase energy and material efficiency (e.g., by better process control through sensor fusion approaches); and (iii) raise the overall technological level by merging electronics and mechanics.

The characteristics of this evolution include:

- Large horizontal integration across multiple value chains on processes, data and companies
- Vertical integration among corporate levels, from the enterprise resource planning (ERP) level down to the field level (sensor and actuators, shop floor)
- A strong interaction by means of the IoT, where connected enterprises can attain increased efficiency in processes, performance and output[20]

SSI technologies will ensure the flexibility to implement changes in process control, accomplishing necessary changes inside and outside the organisation of production, as can be seen by the objectives below.

OBJECTIVE 1 Reduced orders and faster response

It is hoped that SSI will ensure a drastic reduction in the minimum quantity for orders as well as increased speed of response by moving and/or splitting the production departments into coordinated sets of working isles/modules. This move favours greater flexibility of production (improving customisation) through the use of embedded intelligence, and tracking and tracing approaches, in addition to improved human-machine interaction.

OBJECTIVE 2 Moving to a simultaneous model

A transition from traditional production models linked to the concept of "proximity and territorial community" to that of a "simultaneous" model, where global networked manufacturing is an essential and integrated element of production strategy, would be a welcome benefit arising from SSI technologies.

OBJECTIVE 3 Increasing local optimisation

This involves carrying out greater local optimisation underpinned by local knowledge bases, including the examination of raw materials, processes and parts, and thereby suggesting subsequent machine settings to compensate for variation by using improved human-machine interaction together with information on demand strategies. This would help provide workers with useful data from the cloud depending on the situation.

OBJECTIVE 4 Enhanced inline and online use

SSI technologies can improve manufacturing processes by moving test and inspection from offline to procedures that have an inline and online basis through the use of embedded systems and wireless networks.

OBJECTIVE 5 Improving machine parameters

This advance would depend on optimising machine parameters based on measured product performance through cloud computing and evolving big data concepts.

19 *Stephanie S. Shipp, "Emerging Global Trends in Advanced Manufacturing", Institute for Defense Analysis, March 2012.*

20 *Lopez Research, "Building Smarter Manufacturing with the Internet of Things (IoT)", IT World Canada, 2014.*

3.3.2 STRATEGY

Manufacturing technologies can benefit from this approach to turning ideas into products. However, in SSI technology is used to develop customer-specific solutions that can also be produced cost-effectively at medium lot sizes. SSI was driven first by communication and later by automotive applications. To date, SSI has been too focused on developing stand-alone systems in which components are integrated retrospectively into the overall system (such as vehicles and machines). In the future, we can expect the seamless merging of multi-functional electronics and the overall system. It follows that the SSI approach to developing application-oriented multifunctional electronics will begin with the end-product and its functional requirements. In particular, the synergy between application industries and suppliers of electronic functionalities is expected to give rise to great potential for innovation (see Figure 9). Comprehensively implementing this approach necessitates new technologies and changes to the product development process. Thus, the following R&D&I challenges can be identified.

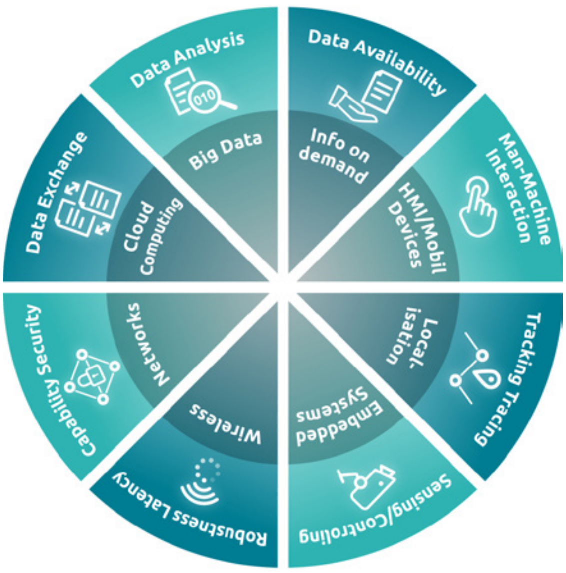


Figure 9: Trends in manufacturing innovations (inner circle) and research task in SSI technologies (outer circle)

STRATEGY 1 HMI/mobile devices for human-machine interaction

- Virtual and augmented reality in R&D, manufacturing, maintenance, etc (wearables for operator support)
- Networked factories (multimedia HMI for increased autonomy of machines and robots)
- Enhanced support and better ergonomics (e.g., by exoskeletons)
- Activity and health recognition (i.e. via smartwatch, emergencies, stress level)

STRATEGY 2 Tracking-localisation

- Identification of serial and IoT ID numbers
- Real-time stock tracking with indoor GPS
- Route optimisation, scheduling and dispatching
- Theft reduction/virtual inventory

STRATEGY 3 Embedded systems – sensing/controlling

- Architecture model for smart systems in an I.4-0 environment
- Interfaces for simulation, testing and validation of design decisions during development
- Modularised toolbox concepts for embedded systems with target of plug-and-play solutions and clearly described (semantic) functionalities for further data use
- Wireless multi-sensor networks, ready for autarkic operation (e.g., by energy harvesting and/or low power sensors, especially chemical sensors)
- (Multi-) sensor with respect to data fusion concepts for data from different sources due to accuracy
- Life-cycle data recorder with physical IP protection/data partitioning due to data ownership
- Multi-channel machine data recording (e.g., for a first time, right in slot, one size environment)
- Concepts for self-control and self-repair
- Integrated power electronic devices (power plus signal processing plus wireless)

STRATEGY 4 Wireless – robustness, latency, energy efficiency

- Robust hard-, firm- and software for real-time applications (command variable 1ms)
- Global system for mobile (GSM) communication, wireless local area network (WLAN), industrial, scientific and medical (ISM): multi-frequency toolboxes, parallel solutions for different levels on bandwidth, latency, energy demand, range, robustness, security
- Responsibility and liability of entities/applications/vendors by electromagnetic (EM) fingerprint;
- Deterministic behaviour of complex systems (plug and connect)
- Interference sources in demanding environment: high-voltage transmissions, welding machines, magnetic fields from electrical motors, semiconductor factories, parallel use of frequencies

STRATEGY 5 Networks – capability, security

- Memory capacity for freedom to determine degree of local data residency
- Smart HW-based authentication (e.g., using physically unclonable functions, PUFs, on the package level, EM fingerprints from node or environment
- HW-based protection against tempering, spoofing and rising attacks against embedded devices
- Energy efficient (HW) security concepts with low latency
- Heterogeneous data items with flexible data structures
- Data distribution service (DDS) as possible middleware
- High-performance bandwidth for data transfer

STRATEGY 6 Big data – data analysis

- Machine-based sensor nodes for predictive/preventive maintenance with miniaturised analogue electronics, data compression and pre-analysis (e.g., for alarming)
- Improved quality with big data cross-correlations (patterns and anomalies): models for describing sensor data with regard to different accuracies, time, etc
- Product-based sensor nodes for lean and six sigma programmes (see also predictive maintenance and life-cycle recorder)
- Information paths for real-time shop floor data up to ERP level
- Distributed (embedded systems) for neural network techniques

3.3.3 IMPACT

Manufacturing is the backbone of Europe's economy. Nearly one in 10 (9.2 %) of all enterprises in the member states of the EU's non-financial business economies were classified as manufacturing in 2012, a total of 2.1 million enterprises. The manufacturing sector employs around 30 million people, and EU countries generated € 1.525 billion of value-added in 2015. State-of-the-art manufacturing technologies are even more important.[21] The European Factories of the Future Research Association considers "Manufacturing [as] an indispensable element of Europe's innovation chain: Manufacturing enables technological innovations to be applied in goods and services, and is key to making new products affordable and accessible". Merging SSI solutions and progress in production technology will deliver sustainable and inclusive growth by creating and ensuring competitive jobs in Europe, as well as supporting a reduction in greenhouse gas (GHG) emissions and improved energy use by efficient production.

3.3.4 ROADMAP

In the following action items evolving from R&D, to demonstration and implementation, into industrial practice, are summarized illustrating selected high-priority topics on the timetable.

ACTIVITY FIELD 1 Cognitive, collaborative systems and autarkic machinery

- Concepts for self-control and self-repair
- Sensors for robot-human co-operation
- Robot-human co-operation

ACTIVITY FIELD 2 Energy efficiency

- Energy logger, intelligent power electronics
- Adaptive control
- Energy footprint reception during production

ACTIVITY FIELD 3 Advanced production technologies

- Additive manufacturing and integrated intelligence
- Lot size 1 CPS
- Lot size 100 CPS

21 Alain Louchez, "From Smart Manufacturing to Manufacturing Smart", Automation World, January 6, 2014.

ACTIVITY FIELD 4 Industry 4.0

- Architecture concepts, tool boxes and sensor fusion concepts
- Machine-based autarkic sensor nodes
- Predictive maintenance for mass products
- Real-time operations supported by smart systems
- Secure and robust machine control
- Product-based autarkic sensor nodes
- Life-cycle recorder

For the roadmap on SSI for manufacturing, the following milestones have been identified (see Figure 10):

Milestone 2020

Hard and software tool box for autarkic wireless sensor nodes

Milestone 2025

Secure and robust cyber-physical systems (CPS) and robot–human co-operation

Milestone 2030

Predictive maintenance for mass products

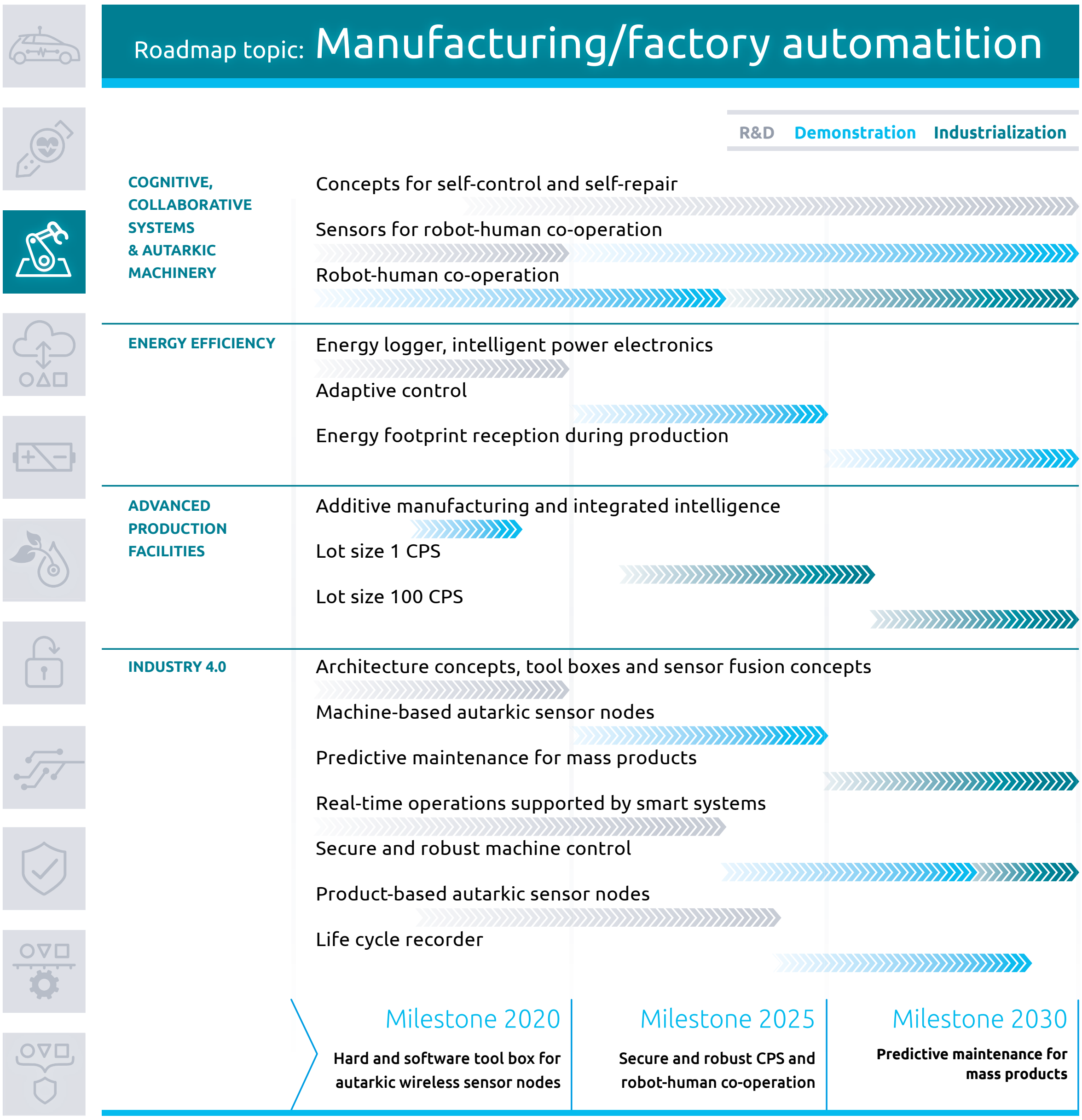


Figure 10: Roadmap for manufacturing/factory automation

3.4 Internet of Things

3.4.1 OBJECTIVES

The possibilities in utilising ICT technologies to monitor and control things in the physical world electronically, together with increasingly available wired and wireless connectivity, will lead to a fully connected world: the IoT. By connecting billions of everyday devices, the IoT combines the physical and virtual worlds, opening up new opportunities and challenges for companies, governments and consumers. The mix of entities will shift over time from "traditional" devices such as smartphones, tablets and wearables to next-generation IoT devices covering all kinds of everyday "connected entities" such as building-integrated sensors, smart door locks, parking meters, road weather sensors to connected cars and implanted heart monitors. Although still early in the new Internet era that has been labelled "the next industrial revolution",[22] this technological mega-trend has already created tremendous expectation, and has the potential to shift fundamentally the way we interact with our surroundings.

The Internet and increasingly open and pervasive connectivity and digitalisation have already become the backbone of modern society, as well as an indispensable facet of everyday life for many. The IoT has the potential to cover all aspects of societal life without exception (e.g., healthcare, home, transportation, industry), and will therefore shape the future.

OBJECTIVE 1 Improve smart system connection

The IoT will help to connect smart systems with the natural, built and social environments, networks for power and data, other smart systems and the human, and thus facilitate the provision and usage of cognitive support to (and from) their surroundings. On the other hand, the IoT itself – as a network of smart sensors and actuators – will be enabled further by smart systems that help develop the network and support integral functions such as wireless connections, energy harvesting, low-cost miniaturisation, and HW-based security, connectivity, self-description, self-awareness and sensor fusion.

OBJECTIVE 2 Changing consumer behaviour

The IoT is changing how users approach goods, moving their interest towards allowable features and functions by means of the technology innovation integrated into "swarm objects". In this way, users are increasingly becoming consumers of services rather than just owners of products.

OBJECTIVE 3 Tackling societal challenges

As stated, the IoT will have a far-reaching effect on many aspects of society, and make possible a wealth of applications in diverse fields. Thus, through enabling the IoT, SSI will contribute to the tackling of societal challenges in all areas. The first IoT applications are already being implemented in health and well-being, agriculture, energy and resource efficiency, security and intelligent transport, while many more are being researched.

OBJECTIVE 4 Boosting inclusiveness and accessibility

The IoT has the potential to boost inclusiveness and accessibility in many daily aspects of life, and can develop as a tool to benefit both innovative and reflective societies.

In conclusion, SSI and its related technologies should be regarded as the key enabler for the IoT, while the IoT is in turn the key promoter of SSI.

22 *http://www.businessinsider.com/iot-ecosystem-internet-of-things-forecasts-and-business-opportunities-2016-2?IR=T*

3.4.2 STRATEGY

Digital access to physical entities is becoming more of a necessity for all kinds of electronic products in the consumer market. Decentrally programmed, globally hosted and globally offered applications (apps) utilising and combining the provided measurement data and/or hardware capabilities of smart systems enable completely new services and business models. Due to this trend and the resulting business opportunities, the required interaction and intervention possibilities with hardware entities are becoming significantly more complex, and are striving for a more sophisticated access to sensors, actuators, electronic products and all kind of connected smart systems.

However, most IoT value chains are still fragmented and only specific business cases are targeted with applications. Most companies focus on particular ecosystems (e.g., the smart home) in offering technology solutions to developers. However, generally these efforts are resulting in vertically oriented (more or less) closed systems and IT architectures.[23] Intra- and cross-sectoral connectivity of smart systems – where sensors, actuators and entities from different hardware providers from heterogeneous market segments are combined – is still only a vision. Although for many years most companies focused on specific technical solutions and many connectivity standards and IT architectures were established, coordination and harmonisation remains widely necessary. The semantic understanding of the offered access to smart systems is still low, but is required to exploit their full potential.

STRATEGY 1 Ensuring HW-secured access and secure connectivity to smart systems

Realising HW-secured access and establishing secure connectivity to smart systems while offering easy authentication routines for *ad hoc* decentral solutions is one of the central challenges of the IoT. Depending on the application area, if this type of approach is not attempted, it results in growing suspicion and distrust.[24] The resulting and still open challenge for smart systems is that low-cost sensors should implement a mixture of authentication procedures, remote updating and patch capabilities, encryption features for data transfer and more, specifically customised for the targeted application and environment.

STRATEGY 2 Improving privacy, trust and data protection

Closely related to the above strategy are issues in the area of privacy, trust and data protection for smart entities. This is especially important as individuals are increasingly have their very personal (health) data monitored and measured by wearables.

STRATEGY 3 The ability to analyse big data

The analysis of the big data produced by billions of entities (sensors, people and organisations) will be one of the greatest challenges for the IoT. It requires data science experts that can extract relevant information and patterns while preserving user privacy and security. This data, combined with machine-learning techniques, could have a major positive impact on the efficiency of industrial production.

STRATEGY 4 Efficient life-cycle management

Expectations for the number of "connected things" vary depending on the study, and the definitions and calculations used, but most anticipate billions of entities in everyday life by 2020. Effective and efficient life-cycle management, including the retrieval and disposal of electronic components, will therefore be of vital importance. Furthermore, longer-term eco- and bio-compatibility should be targeted.

STRATEGY 5 Well-organised energy management

Efficient energy management using low-power computing techniques, integrated energy storage functions, energy harvesting and wireless energy transfer will guarantee (and even enhance) technological life expectancy. Hand-in-hand with the exploding numbers of IoT devices is the growing challenge regarding environment sustainability and the ability to undertake the necessary recycling.

However, two aspects of the IoT are under-considered, partly due to the greater focus on wearables and gadget applications:

- The IoT requires a continuous sensor and actuator development based on a sound understanding of measurement and control for specific application domains

23 AIOTI WG01, "Report on Internet of Things Applications", October 26, 2015.

24 See http://arstechnica.com/security/2015/09/9-baby-monitors-wide-open-to-hacks-that-expose-users-most-private-moments.

- IoT devices need to be designed for, or adapted to, the different environments in which they are used; this, in turn, results in specific requirements for environmental conditions, energy management, communications, etc, in addition to the requirements for sensors and actuators
- Hence, the IoT will develop by sector, but where possible with a maximum commonality of functionality, re-use of building blocks and interoperability (see roadmap milestones).

3.4.3 IMPACT

Forecasts on the number of connected entities by 2020 vary depending on institution, from 20 billion by Gartner,[25] to over 38 billion according to Juniper Research,[26] to Cisco's 50 billion.[27] To view this more tangibly, by 2016 approximately 5.5 million new things will become connected every single day. However, no matter the exact number, there is a common expectation that it will be huge. As SSI is an enabler for the first-level systems (including hardware) to obtain local environmental awareness and provide the requested feedback and actuation for the IoT, it should be assumed that SSI will make a significant contribution to most of these forecasted connected device categories.

R&D&I of smart systems for the IoT will foster interoperability and, very importantly, security in applications. Since the IoT is pervasive in all vertical application fields, smart systems for the IoT as well as the seamless integration of smart systems application into the IoT will help to generate cross-sectorial applications. Thus, all societal challenges will be impacted, new business opportunities will be created and the competitiveness of Europe in this strongly growing field will be strengthened.

3.4.4 ROADMAP

In the following action items evolving from R&D, to demonstration and implementation, into industrial practice, are summarized illustrating selected high-priority topics on the timetable.

ACTIVITY FIELD 1 Integrated security, privacy, trust and data protection solutions for smart systems

- Built-in hardware security features and access routines (bio-authentication features, encryption, protection from unauthorised access, remote updates and patches, etc)
- Integrated security and privacy principles by design for SSI applications

ACTIVITY FIELD 2 Standards, information models and interoperability for SSI

- Develop reference models and IT architecture for cross-sectoral technical modularisation/connectivity of smart systems and other technology
- Information models for self-description (i.e. of data/measurement characteristics and intervention possibilities for semantic interoperability of smart systems)

ACTIVITY FIELD 3 Integrated energy management approaches

- Wireless energy transmission concepts for short-range applications
- Develop low-cost miniaturised 360° energy concepts (storage concepts with batteries or supercaps, i.e. in combination with energy harvesting)

ACTIVITY FIELD 4 Sustainable life-cycle management for smart IoT entities

- Develop retrieval, re-usage and refurbishment concepts for IoT objects, i.e. using eco- or bio-compatible materials
- Integrated design concepts for recycling necessities
- Sensor and actuator development
- Different measurement methodologies:
  - Indirect measurements
  - Sensor array measurements
  - Multi-parameter measurements
- Miniaturised, durable and reliable chemical sensors.

25 *http://www.gartner.com/newsroom/id/3165317.*

26 *http://www.juniperresearch.com/press/press-releases/iot-connected-devices-to-triple-to-38-bn-by-2020.*

27 *http://www.cisco.com/c/en/us/solutions/internet-of-things/overview.html.*

For the roadmap on SSI for IoT, the following milestones have been identified (see Figure 11):

Milestone 2020

Cross-sectoral applications meeting user needs

Milestone 2025

Interoperable, horizontal and secure applications

Milestone 2030

Self-aware entities recognise events and changes in their environment, and sense and react autonomously

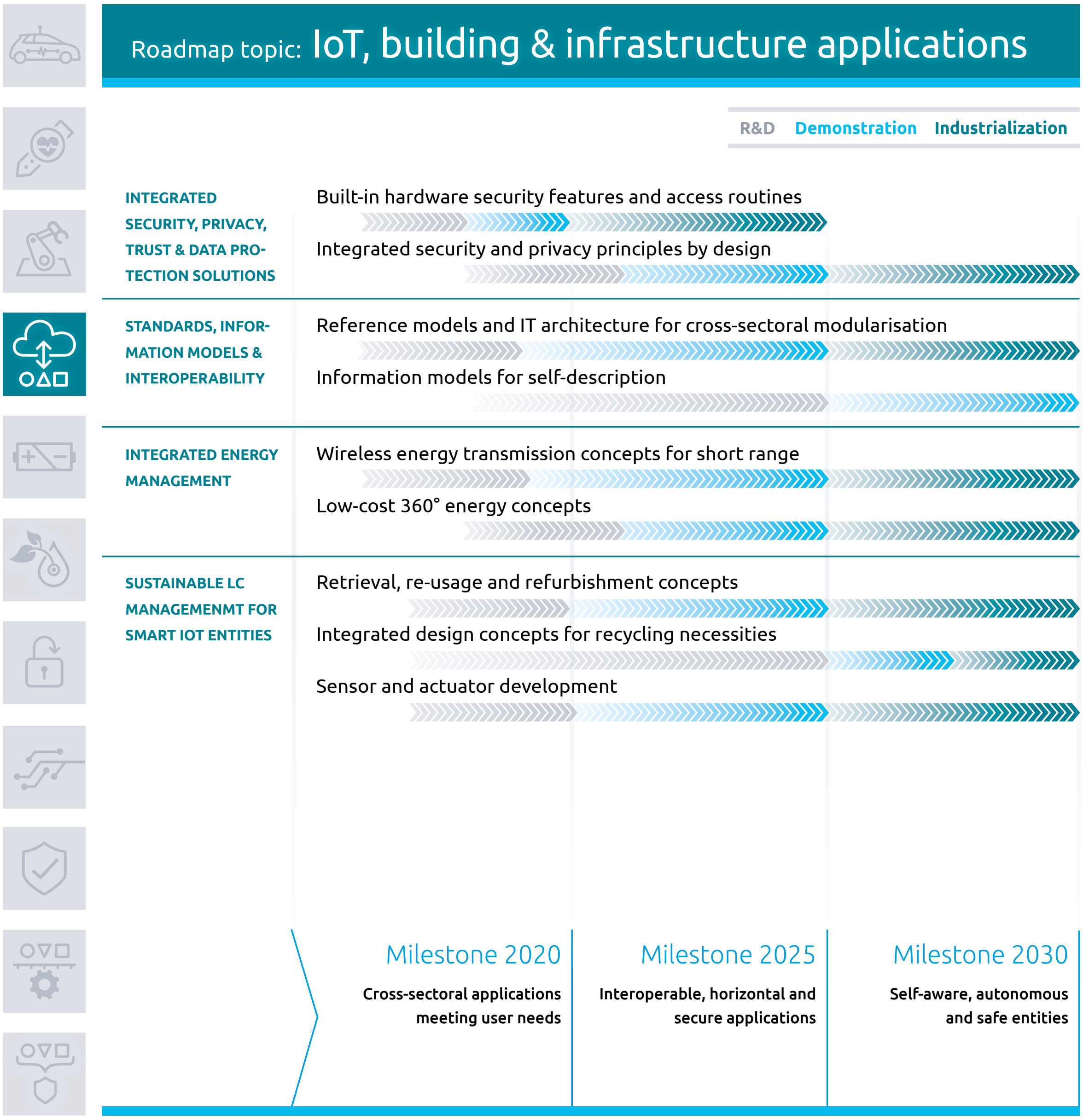


Figure 11: Roadmap for IoT

3.5
Energy

3.5.1 OBJECTIVES

OBJECTIVE 1 Reducing non-renewable energy consumption

The key objective for the introduction of smart systems in energy applications is a significant reduction of non-renewable primary energy consumption to reduce GHG emissions. The goal is to meet growing global energy demand by means of climate and ecologically friendly energy systems that provide a clean, safe and reliable energy supply.

Smart system-based devices are key enablers for achieving higher energy efficiencies and an intelligent use of energy along the whole energy value chain, from generation to distribution, storage and consumption.[28]

OBJECTIVE 2 Improving energy efficiency while reducing consumption

Enhancing energy efficiency and sustainability in generation while reducing energy consumption and significantly lowering the carbon footprint are driving forces for R&D in embedded and integrated smart systems. They help secure a balance between sustainability, cost-efficiency and security of supply in all key energy applications – transport, manufacturing, food production and buildings.

The introduction of SSI in energy applications meets the challenge of providing clean energy when and where it is needed within safe, efficient and resilient energy systems, and to reduce the total consumption of energy by:

- Increasing the energy efficiency along the whole energy value chain
- Real-time monitoring of energy consumption and carbon footprint through the use of smart meter communication infrastructure and technologies
- Improving grid operation and availability while respecting safety margins
- Enhancing systems reliability through smart monitoring of the ageing of components
- Increasing safety, reliability and resilience of smart grids by smart control and management systems (home/building energy management systems)
- Improving the effectiveness and controllability of renewable energy sources and loads
- Using smart solar inverters and smart functionalities to link inverters to electricity consuming and storage devices in homes or commercial premises
- Improving grid integration of renewable energy sources, both distributed and centralised
- Decentralising load management systems
- Maximising the use of existing power infrastructure through better monitoring and energy management
- Controlling bi-directional charging of electric and hybrid vehicle batteries

3.5.2 STRATEGY

Three key energy domains will be the focus of upcoming research for SSI and therefore a key part of strategic expectations in the sector.

STRATEGY 1 Sustainable power generation and energy conversion

STRATEGY 2 Reducing energy consumption

STRATEGY 3 Innovations in efficient community energy management

The new integrated Strategic Energy Technology (SET) plan stipulates a "smart EU energy system, with the consumer at the centre". It requires smart solutions for homes and businesses, and a smarter energy system based on a combination of ICT and energy technologies.

Research targets have to cover innovations in further enhancement of efficiency, reduction of consumption and the miniaturisation of system sizes. Along with new applications, the demand for highly reliable and robust devices in a smart grid as a system-of-systems to enable highly efficient use of energy is a top-level research issue. The potential of digitalisation and new topologies has to be leveraged to achieve significant energy savings, keeping costs down and comfort up. The necessary innovations in SSI for energy applications require

28 *Roger Harrabin, "Smart Energy Revolution 'Could Help to Avoid UK Blackouts'", BBC News, August 31, 2016.*

applied research, including validation (TRL 2-6) and prototyping (TRL 6-8). Development and pilot projects can address these areas. Furthermore, research activities, developments and demonstration scenarios should be open to different application scales (home, building, district, city). The R&D&I challenges and needs regarding SSI in energy applications, and the expected results, are shown in Table 1.

OBJECTIVE	CHALLENGE	R&D&I ACTION	IMPACT (SOCIETY/ECONOMY)
SUSTAINABLE POWER GENERATION	Growing energy demand – renewables supported by SSI	▪ improvement of energy efficiency ▪ lifetime and robustness ▪ new materials/production processes ▪ reduced life-cycle cost with smart maintenance, including waste treatment ▪ scavenging and recycling	▪ higher energy efficient, local employment through smallscale local production ▪ enhanced safety and reduced waste ▪ competitive position of European energy industry over full value chain ▪ strategic and economic energy independence
EFFICIENT CONVERSION	Efficient distribution and storage of energy	▪ smart converters ▪ DC grid components ▪ adaptive interfaces	
REDUCED CONSUMPTION	Sustainability, enhanced system efficiency, reuse/ recycling	▪ efficient usage by smart consumption management ▪ smart metering/controls ▪ combined heat and power/waste heat recovery	▪ less dependence on energy sources, reduced energy costs, reduced energy poverty ▪ new market for control systems and efficient appliances
SMART ENERGY MANAGEMENT ON COMMUNITY LEVEL	Efficient management of demand, distribution and secure supply	▪ self-organised grids and multi-modal energy systems, including storage ▪ smart applications for sharing communities ▪ energy efficient buildings, home energy management system (HEMS), building energy management system (BEMS), IoT	▪ elimination of waste energy ▪ higher efficiency at lower costs ▪ new business models for decentralised services with local employment ▪ new markets for infrastructure control systems ▪ competitive position of European energy value chain ▪ prosumer and citizen empowerment

Table 1: R&D&I challenges

3.5.2 IMPACT

Research for the introduction of SSI in energy applications must support the EU target for 2020 of saving 20 % of its primary energy consumption compared to projections.[29] On November 30, 2016, the European Commission restructured its energy efficiency package to propose a 2030 binding energy efficiency target of 30 % for the EU as part of its updating of the Energy Efficiency Directive to ensure the new target is met. With innovative research at the European level, the leading position will be strengthened and further employment secured. Therefore, research has to address:

- The reduction/recovery of significant losses (applications and service-oriented applications (SoA) related)
- Decreased size of systems through miniaturisation and integration
- Increased functionality, reliability and lifetime (by including sensors/actuators software, etc)
- Increasing market share by introducing (or adopting) disruptive technologies
- Transition to distributed renewable energy sources and decentralised networks (including micro-grids)
- Plug-and-play integration of smart components and systems
- Safety and security issues in self-organised grids and multi-modal systems

The introduction of SSI for energy applications regarding components, modules, CPS, service solutions, etc, that support the EU and national energy targets will have a huge impact on employment generation and education if fully developed in Europe.[30] The key will be the capability to have complete systems understanding and competence for small-scale solutions up to a balanced energy supply for regions. Mandatory are the capability for plug-and-play of the components enabling a broad research contribution from SMEs, service providers up to top leaders in the energy domain. SSI will provide solutions enabling consumers to better participate in (energy) markets as foreseen by the European Energy Union priority. Societal impacts to be achieved and how they relate to EU objectives and R&D&I actions are summarised in Table 1.

29 Energy Efficiency Plan (Com 2011-109).

30 D. Connolly, H. Lund and B. V. Mathiesen, 2016, "The Technical and Economic Impact of One Potential 100% Renewable Energy Scenario for the European Union", Renewable and Sustainable Energy Reviews, 60, July, pp 1634–53.

3.5.4 ROADMAP

To achieve the objectives of a broad introduction of smart climate and ecologically friendly energy systems throughout Europe, further R&D&I efforts should be made (see Table 1). In the roadmap below, four major activity fields for research and innovation within the next 15 years are addressed.

ACTIVITY FIELD 1 Sustainable power generation and energy conversion

Power generation and energy supply needs to be sustainable, reliable and resilient. Power generation must preferably (and eventually exclusively) be accomplished through renewable energy sources and cover the increasing overall demand. Safety and security concerns must be addressed.

ACTIVITY FIELD 2 Efficient energy conversion

Smart converters are key elements of efficient transmission, distribution, conversion and storage in the AC/DC and DC/DC grids of the future. This includes local intelligence (sensors, actuators, control) and communication infrastructure that will then form smart adaptive grid interfaces.

ACTIVITY FIELD 3 Reduction of energy consumption

Optimised energy usage over all sectors requires smart components and intelligent services. Combined heat and power, and finally multi-modal energy systems, allow higher utilisation of energy; waste heat needs to be recovered. Key issues for smart consumption management are smart metering and controls.

ACTIVITY FIELD 4 Creation of smart energy communities

Increasing utilisation of distributed renewable energy sources leads to decentralised energy supply systems with empowered consumers at the centre. SSI-enabled energy appliances will be able to scavenge and store, monitor and inform, learn and predict, control and decide, bid and negotiate, anticipate and respond. To manage increasing complexity, self-organised grids and multi-modal energy systems (including storage) are needed on all grid levels. Key elements will be smart applications for sharing communities, energy-efficient buildings connected via an IoT.

The roadmap thus specifies actions that should be performed and the type of smart systems in certain states of technology maturity that should be introduced in each activity field to reach the milestones for 2020, 2025 and 2030 described below (see Figure 12):

Milestone 2020

Smart system technologies for energy applications are developed and implemented to secure a 20 % reduction of GHG emissions and energy consumption. This implies the following objectives:

- Reduction of GHG emissions and energy consumption by 20 %
- Increased share of renewables to 20 %
- Decentralised simple connected systems with first integration approaches, including power system services

Milestone 2025

European manufacturing industries being ready to supply SSI for energy applications; R&D is completed for SSI for smart energy management in regional area networks. This implies the following objectives:

- Supply of SSI for energy applications by European manufacturing industry secured
- SSI capable of fast, energy-efficient management of surplus supply and peak load situations
- Regional area balanced energy supply (villages and cities up to 100.000 users)

Milestone 2030

Demonstration phases are widely completed and industrialisation of SSI for energy applications is advanced such that energy supply in EU is balanced with a share of at least 45 % renewable energies. This implies the following objectives:

- Share of renewable energy in the electricity sector should be increased from 20 % to at least 45 % in the energy mix at EU level
- Balanced energy supply at a country level with functional EU interfaces[31]

31 *"Energy Efficiency Plan 2011" (COM(2011) 109 final); "A Roadmap for Moving to a Competitive Low Carbon Economy in 2050" (COM(2011) 112 final); "Energy 2020 – A Strategy for Competitive, Sustainable and Secure Energy" (COM(2010) 639 final); European Energy Union (available at http://europa.eu/rapid/press-release_MEMO-15-4485_en.htm); "Towards an Integrated Strategic Energy Technology (SET) Plan"; "Towards a New Energy Market Design" (2015/2322(INI)).*

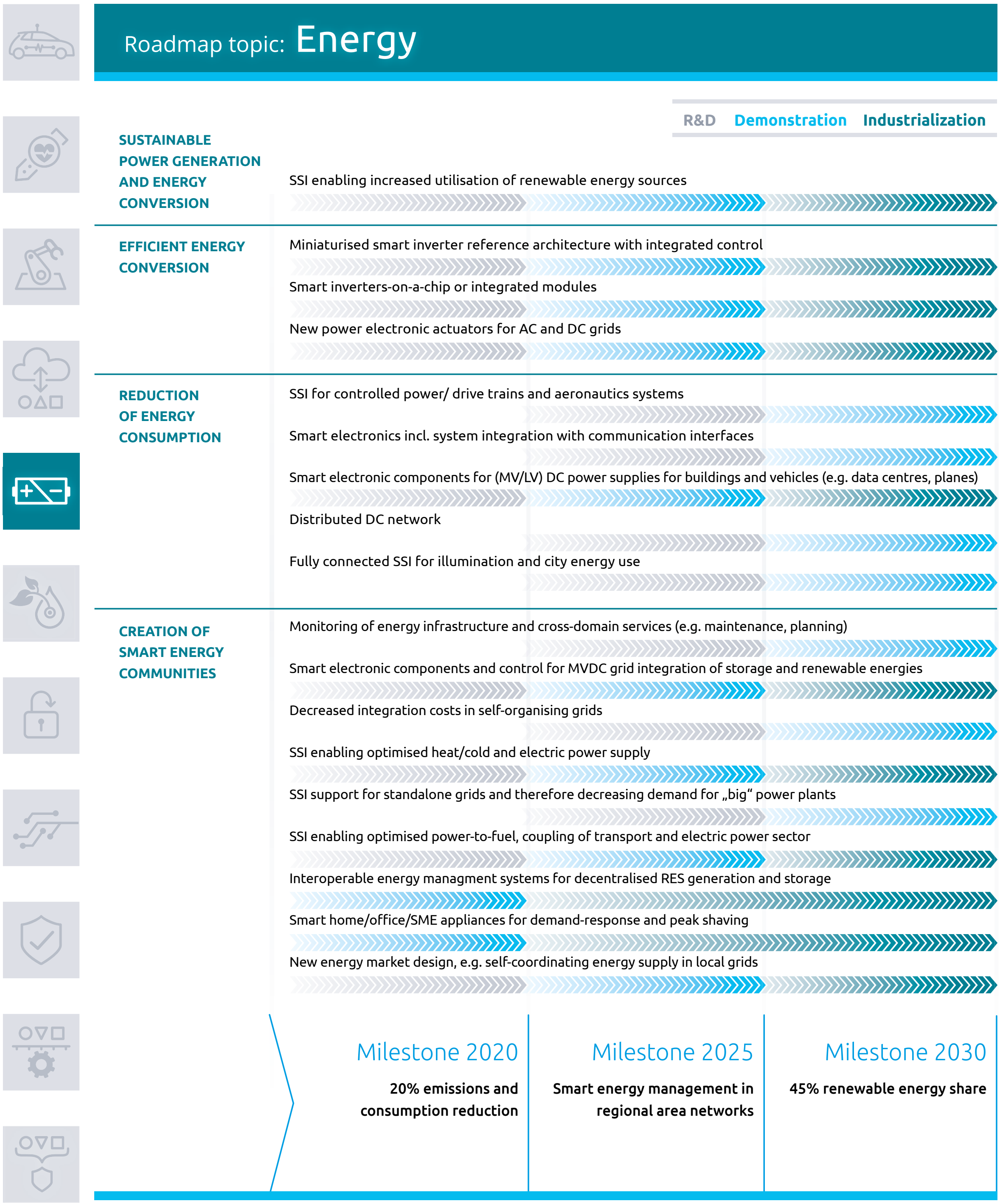


Figure 12: Roadmap for energy

3.6

Natural resources

3.6.1 OBJECTIVES

The application field "natural resources" addresses the sustainable management of raw materials, water and food along the full value chain, supporting the European flagship initiative on a resource-efficient Europe.[32] Within this initiative, innovations are required for resource efficiency and productivity to decouple economic growth from the use of resources, and to transform Europe towards a green economy. Among the manifold topics and challenges addressed in the "Roadmap to a Resource Efficient Europe" report, raw materials, water and food were seen as resources where smart system technologies could have a significant impact on meeting the specified challenges. The initiative states that resource efficiency needs to be increased by between a factor of four and 10 by 2050 to meet the demands for raw materials, water and food. Essential raw materials are already scarce, and their price volatility is having a negative impact on national economies. Apart from increasing the recycling and re-use of those materials (six tonnes of materials per person are wasted annually), new sources for raw materials have to be unlocked. With respect to food, a 70 % increase in demand is predicted by 2050, whereby "60 % of the world's major ecosystems producing these resources have been already degraded or are used unsustainably". Furthermore, water as a low-cost good is currently underestimated, although "recent analyses predict that by 2050, three billion people will suffer from water scarcity and that worldwide about 200km^3 storage capacity will be required by 2025".[33] Within Europe, at least 17 % of the population are already experiencing water scarcity.

In the following, the role of smart systems for securing the availability and increasing the efficiency of raw materials, water and food are described.

OBJECTIVE 1 Meeting the demand for raw materials

Exploiting new resources: 10 %[34] of the world's minerals will be exploited and mined from sea by 2030. A special focus is given to deep sea mining, where the biggest natural mineral resources are expected. To exploit these resources, remote controlled vehicles (ROVs) and automated vehicles are needed for imaging and identification, sampling, exploitation and processing (see roadmap).[35] This needs to be done based on a sustainable approach without endangering deep sea bio-diversity. Innovative technologies are needed to withstand the harsh environment, such as smart robotic manipulators or smart maintenance concepts (smart sensor systems and data processing, self-repair) for the ROVs and automated vehicles, and for self-sustaining, robust diagnostics and monitoring of the environment and exploration processes to avoid damages to biodiversity.

The efficient recycling and re-use of materials is also key. For this, and to help minimise the use of materials in products, detailed knowledge over the entire lifetime is crucial. Thus, materials need to be sensorised and monitored over the full product life-cycle. Both are cornerstones of the so-called "material data space"[36] within Industry 4.0. Furthermore, in the recycling process different materials need to be identified and separated by automated systems, again requiring smart sensor systems and precise processes for separation (including robotics).

32 European Commission, "Roadmap to Resource Efficient Europe", COM(2011) 517 final.

33 The European Water Platform (WssTP), "Strategic Research Agenda – A Common Vision for Water Innovation", 2010.

34 European Commission, "Blue Growth – Opportunities for Marine and Maritime Sustainable Growth", COM(2012), 497 final.

35 DG MARE,, "Blue Growth – Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts; Marine Sub-function Profile Report Marine Mineral Resources (3.6), Call for tenders No. MARE/2010/01", European Commission, Rotterdam/Brussels, August 13, 2012.

36 R. Wehsporn, „Material Data Space – Eine Initiative zur Implementierung von Industrie 4.0 in Werkstoffintensiven Wertschöpfungsketten, Fraunhofer" position paper, 2016.

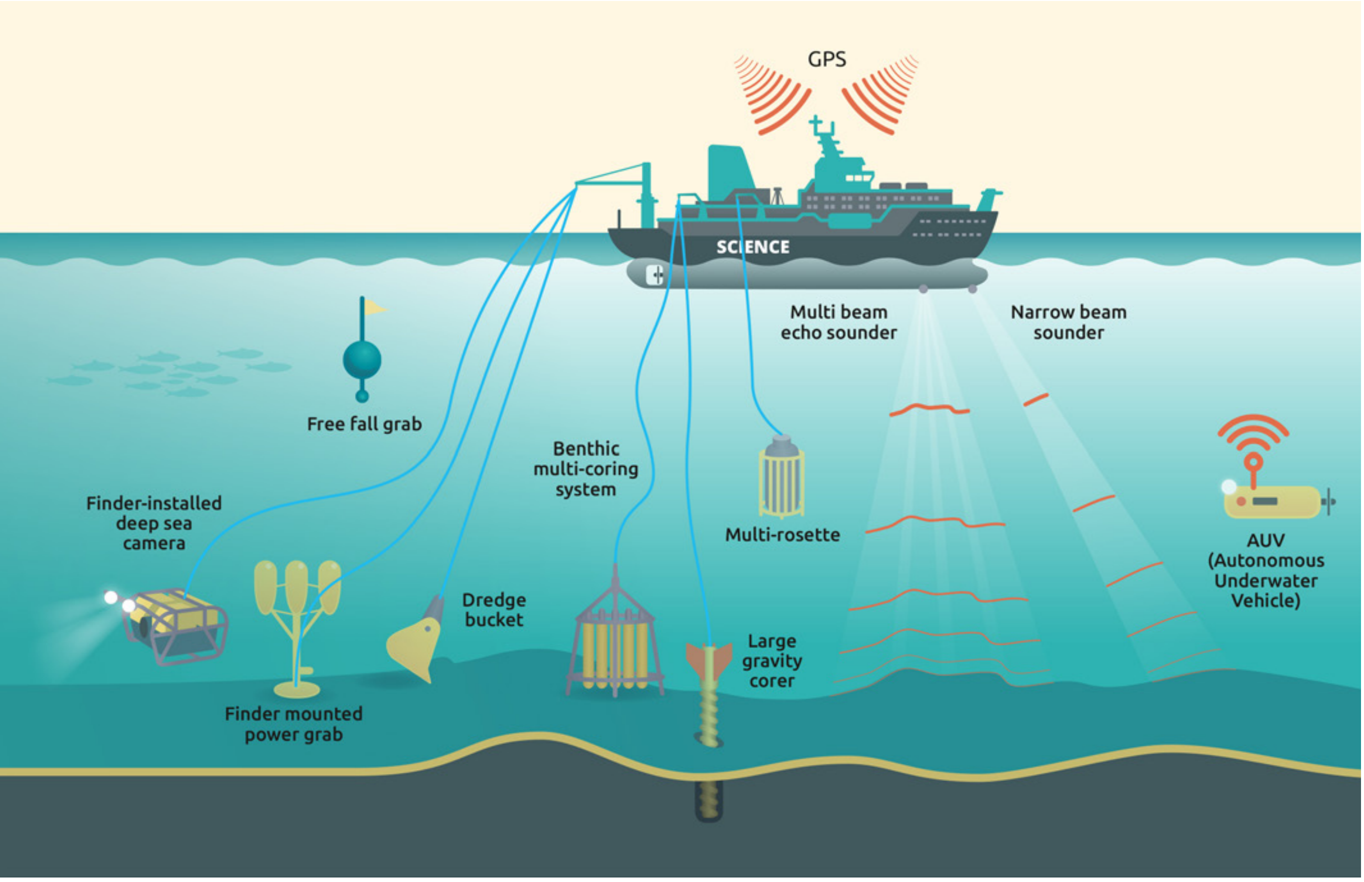


Figure 13: Examples of exploration techniques and tools[37]

OBJECTIVE 2 Ensuring water quality and improving how it is managed

This objective focuses on the quality of water and its sustainable management. In terms of water quality, droughts and floods will either impact or endanger the quality of water bodies (surface and ground water) and thus also the water quality in daily use by people.[38] In addition, the overaged and deteriorating water infrastructure is impacting water quality. Smart systems can support the integrity of our water quality by providing sensors and online monitoring systems to detect low levels of chemicals and microbiological contamination throughout the distribution systems. Furthermore, diagnostic and monitoring systems are needed for surface water bodies (oceans, seas, lakes and rivers) to protect our bio-diversity from contamination (micro-plastic and other waste, chemicals, microbiological). Finally, purification, re-use of waste water and desalination (the last is of particular importance for coastal areas) will become a challenge in the future, and smart system technologies (sensing, diagnostics, etc) can support cost-efficient solutions.

For sustainable water management, its distribution and efficient use is paramount. With respect to distribution, demand and supply needs to be balanced, requiring smart water distribution systems. For this, smart sensor and monitoring systems and intelligent distribution networks offer new opportunities. Taking the aged and deteriorated water infrastructure additionally into account, sensor systems are particularly necessary for detecting leakages. In terms of efficiency, smart metering technologies are required to promote efficient use of water. Water is also heavily used in production processes, in many cases as a cleaning agent without much control. Smarter *in situ* control of cleaning water status will help sustainability, avoiding open-loop cleaning processes.

37 *"Study to Investigate the State of Knowledge of Deep Sea Mining: Annex 4 – Final Report Technology Analysis", FWC MARE/2012/06 – SC E1/2013/04, 2014.*

38 *The European Water Platform (WssTP), "Strategic Research Agenda – A Common Vision for Water Innovation", 2010.*

OBJECTIVE 3 Using smart system technology to improve food production and distribution

The element of this objective is sustainable production. According to the "Food for Life Strategic Research Agenda",[39] innovative technologies are required to enhance productivity, efficiency and sustainability to make the bio-economy viable. In this context, food production affects the three pillars of sustainability: environmental, economic and social. For example, in agriculture smart system technologies will play an increasingly important role in water management (see above), monitoring farming conditions and enhancing the effectiveness of fertilisation and pest control to minimise the environmental impact. The latter can be done either through a smart distribution network capable of diagnosing a need and, for instance, releasing fertiliser or pesticide in the desired quantity, or through automated or unmanned aerial vehicles. Besides agriculture, aquaculture is gaining greater attention as a means to meet the demands for food. In 2016, € 1.2 billion of investments were allocated to the aquaculture sector alone.[40] In the long term, automation and the smart operation of marine biological production and harvesting systems are required to minimise their environmental impact. This again includes smart networks with automated feeding, monitoring of growth rates, health and water quality.[41]

The second element is ensuring food safety and quality along the operational food chain.[42] This includes the prevention and control of specific hazards, traceability, authenticity and food defence (adulteration and bioterrorism), either on- or at-line. The quality of food must be monitored along the distribution chain as well to ensure that only food of sufficiently high quality reaches consumers. Both require sophisticated sensor and monitoring systems to be applied in a straightforward way throughout the food chain.

3.6.2 STRATEGY

Smart systems for natural resources have not been applied widely to date. Research on advanced smart systems for the diagnosis, monitoring, exploiting, harvesting and efficient use of raw materials, water and food is just beginning. In water management, sensor and monitoring technologies have been considered over the last few decades but they "were neither mature nor cheap enough to be deployed in large quantities".[43] However, early examples can be found where smart systems have been applied in farming, such as the wireless asparagus monitoring system of Bosch (see Figure 14).[44]

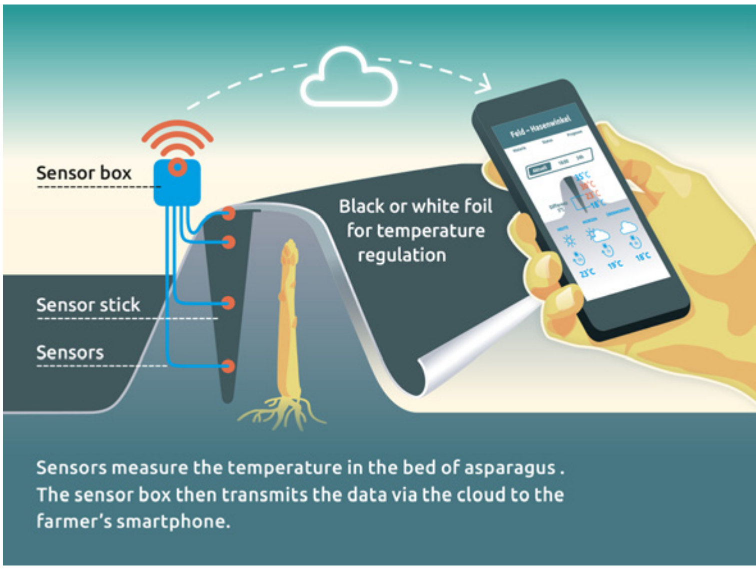


Figure 14: Bosch asparagus monitoring system[45]

The potential applications for smart systems for natural resources can be divided into two research areas:

- Smart sensor and monitoring systems with diagnostic capabilities to ensure resource efficiency and safety, as well as to minimise the environmental impact along the full value chain
- Automated or remote controlled production or exploration of natural resources

Such uses are also known from other areas that allow synergies between different applications, such as diagnostic systems from health applications or automated vehicles within the transport sector.

39 *European Technology Platform Food for Life, "Strategic Research Agenda 2007–2020".*

40 *European Commission, "Aquaculture in the EU – Tapping the Blue Growth", 2016.*

41 *JPI Ocean, "Strategic Research and Innovation Agenda 2015–2020".*

42 *European Technology Platform Food for Life, "Strategic Research Agenda 2007–2020".*

43 *The European Water Platform (WssTP), "Strategic Research Agenda – A Common Vision for Water Innovation", 2010.*

44 *Deepfield Connect, "Asparagus Monitoring" (available at http://www.deepfield-robotics.com/de/Deepfield-Connect-Casestudy.html).*

45 *ibid.*

STRATEGY 1 Adapting to specific circumstances

Specific smart systems in the context of deep sea mining, material data space, of water quality and management as well as food production, safety and quality need to be adapted to the special environment in which they operate, and in most cases these are harsh and unpredictable. Thus, in the considered applications a significant integration in protecting structures is required. Particularly in deep sea mining, very harsh conditions exist that demand new sensors and actuators as well as novel conceptual designs and materials to facilitate robustness and reliability. Also, communication within networks or between automated or remote control vehicles poses a challenge and significant research is required. With respect to the diagnosis and detection of various contaminations for water and food, completely original sensor systems are needed with sufficient sensitivity under harsh or undefined conditions. With the exception of deep sea mining, the smart sensor and monitoring systems for natural resources will be applied with cost-sensitive and low-value systems, as shown by the roadmap below. Indeed, cost-effective solutions are important for the large-scale deployment of smart systems for natural resources without sacrificing robustness and reliability. Finally, miniaturisation, self-diagnosis and energy autonomy (since no external power source is available) are essential features of the smart sensor and monitoring, posing significant R&D&I challenges.

STRATEGY 2 Fit for purpose concepts

Regarding automated or remote controlled production or exploration, the R&D&I challenges are very broad and dependent on the application. In deep sea mining, vehicles that can operate on the ground as well as being able to swim are required. This involves new types of positioning sensors and gyroscopes, and more complex control strategies than for surface-based automated vehicles. In agriculture, automated farming vehicles will be used for fertilisation and pest control, leading to miniaturised aerial vehicles (note, automated, land-based vehicle for farming will not be addressed here). In this context, innovative technologies need to be developed for all required sub-systems, such as engine and power supplies, flight control, integrated sensors and diagnostic systems. Alternatively, smart, fixed installed distribution systems can be applied, which require research on their dosing systems, smart valves and energy supply.

3.6.3 IMPACT

Smart systems for European resources support directly the objectives outlined in the Resource Efficient Europe initiative. As enabling, cross-cutting technology, smart systems complement various measures to increase efficiency in the use of, and to meet the still-growing demand for, natural resources – particular regarding raw material, water and food. They will contribute to reducing waste as well as exploiting it as a resource, and employing new sources for raw materials and ensuring a high quality of water and food. Particular smart systems will allow for minimising environmental impact while producing and distributing raw materials, water and food. Thus, smart systems will become essential in constraining the loss of bio-diversity, and in maintaining or improving our quality of life. However, as an enabling technology it is difficult to quantify properly the impact smart systems will have on resource efficiency.

Nevertheless, natural resources offer a new field of application for smart systems. Raw materials, water and food represent a multi-billion euro market in which large investment will be made over the coming decades. It is reasonable to assume that smart systems, and in particular smart sensor and monitoring systems, will participate significantly in these markets. As such, R&D&I on smart systems for natural resources will contribute to job creation in the European smart systems industry and strengthen its competitiveness, as well as providing economic growth within the EU.

3.6.4 ROADMAP

In the following action items evolving from R&D, to demonstration and implementation, into industrial practice, are summarized illustrating selected high-priority topics on the timetable.

ACTIVITY FIELD 1 Smart systems for deep sea mining

- Design of reliable, robust sensors and monitoring systems for probing, analysing and monitoring environmental impact in deep sea mining operations
- Development of smart remote controlled or automated vehicles for deep sea mining
- Smart system-based maintenance and repair strategies for deep sea vehicles
- Test and validation methodologies for smart systems in deep sea mining

ACTIVITY FIELD 2 Smart systems for circular economy

- Novel sensors and systems for life-cycle monitoring of materials
- Cost efficient sensor and system integration for life-cycle monitoring
- Sensors and systems for material identification in recycling process
- Smart systems for automated separation of multi-material systems

ACTIVITY FIELD 3 Smart systems for ensuring high water quality

- Development of sensor and diagnostic systems permanently installed in water systems
- Concepts for cost-efficient, large-scale integration into water systems
- Concepts for self-calibrating, data fusion and online assessment of measured data (cloud-based)
- Upscaling of production

ACTIVITY FIELD 4 Smart systems for efficient water management

- New, miniaturised reliable sensors and diagnostics for water distribution systems
- Smart, intelligent valves and metering systems for water distribution systems
- Cost-efficient, manufacturing and assembly concepts for large distributed sensor and monitoring systems

ACTIVITY FIELD 5 Smart systems for sustainable food production

- Design of sensor networks for monitoring of farming and aquaculture conditions, including growth rates
- Development of sensors able to measure the demand of fertiliser or feed, or pest infestation
- Development of smart, intelligent distribution systems for water, fertiliser, feed and pesticides, including aerial vehicles
- Development of automated harvesting in agriculture and aquaculture

ACTIVITY FIELD 6 Smart systems for food quality and safety

- Development of miniaturised sensors for food quality and safety
- Design of smart systems for automated quality control along the food chain and distribution control
- Design of smart systems for prevention and control of specific hazards, traceability, authenticity and food defence

For the roadmap on SSI for natural resources, the following milestones have been identified (see Figure 15):

Milestone 2020

Applied research on advanced smart systems for natural resources taken up widely by industrial stakeholders, reaching up to TRL 4

Milestone 2025

Wide spectrum of solutions for smart systems for natural resources demonstrated in field tests

Milestone 2030

Smart systems widely used in deep sea mining, for water quality and management, and food production and quality

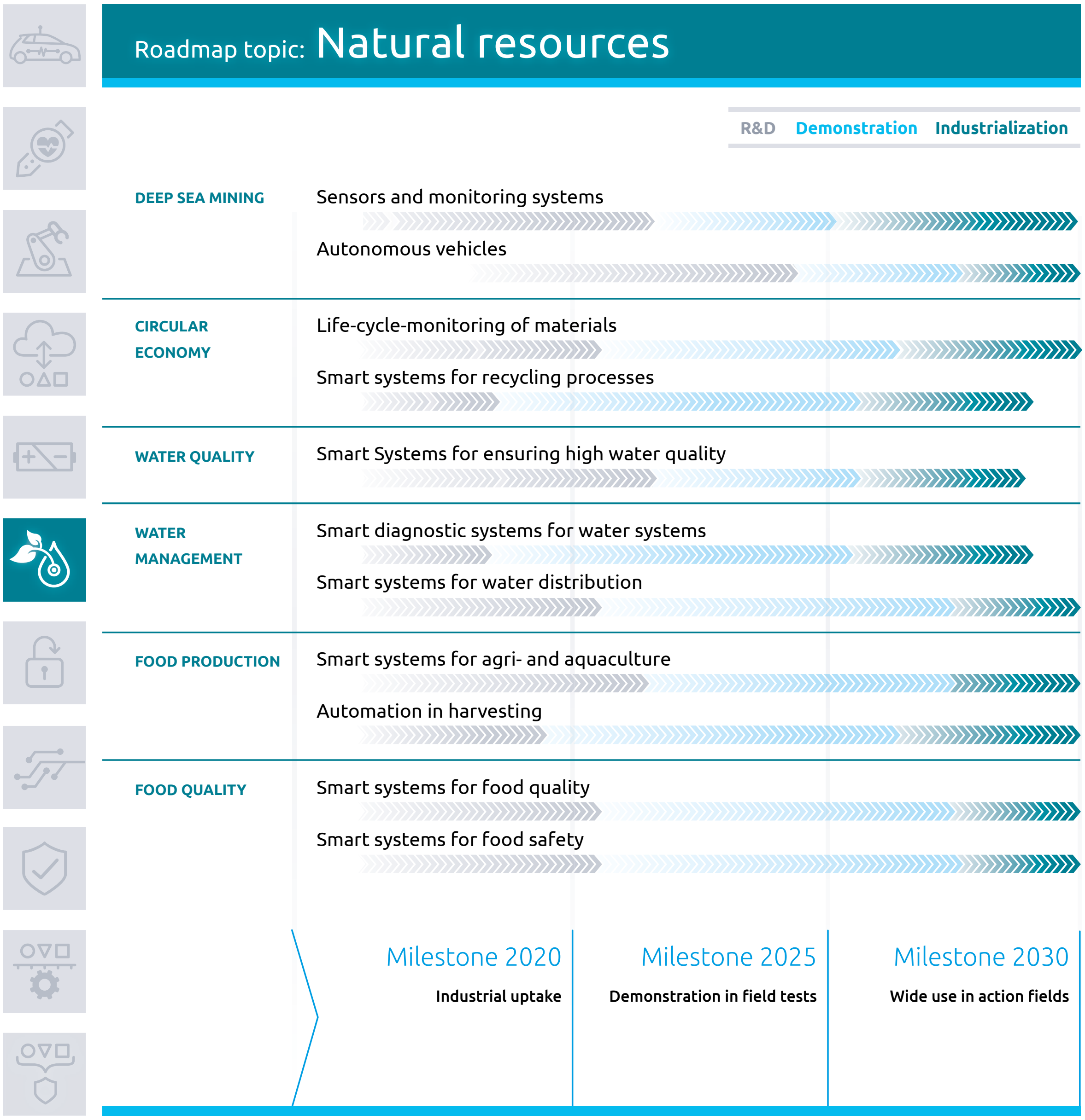


Figure 15: Roadmap for natural resources

3.7
Security

3.7.1 OBJECTIVES

There is an increased need for means to support security at home, at private buildings and campuses, in public buildings and spaces, for public transport, etc, using increasingly sophisticated ICT technologies.

OBJECTIVE 1 Introduction of measures to prevent threats

SSI technologies have a role to play in improving a range of security aspects. These include limiting dangerous situations for people, the detection of and prevention against intrusion, unauthorised access to spaces and goods, theft and falsification, and combating terrorist activities, including the detection of weapons and explosives.

OBJECTIVE 2 Development of smart sensors

An attractive proposition for many general-purpose security systems is the use of smart, multi-parameter sensors, including photonic sensors such as vision. Such sensors, when combined with information from other sources, can be fed into combinatorial analysis software at the "platform" level. In particular, smart sensors constitute an application domain of excellence for SSI, where the latter is a key enabler.

3.7.2 STRATEGY

Security as a service builds on smart sensor nodes and combinatorial analysis at the "platform" level, combining smart sensor information with general IoT information. However, although sensors – such as those optimised for sensitivity or high contrast (for gases, radiation, etc) – may benefit from the IoT, it is a smart system in itself. For example, intrusion can be detected by combining the information from smart presence detectors with high selectivity (flies, birds and rats, for example, should be detected or ignored depending on the objectives of a specific application), and measuring suspect increases in electric energy consumption.

STRATEGY 1 Using the IoT for security

The strategy for SSI in security can employ the IoT as a basis with a range of extensions, some of which will be specific to the application domain; a class of smart sensors for security will indeed have much in common with other application domains – for example, sensors for smart vehicles/autonomous driving. Specific smart sensors for security may also be rather sophisticated and exist in the high-end domain, such as pattern or face recognition.

STRATEGY 2 Ensuring high standards for secured communication

Smart sensors for security and most other equipment for security applications must meet high standards in terms of secured communication and content, resistance to physical and other attacks and redundancy (see roadmap below).

Whereas the applications, and thereby the architecture, of security systems is relatively well-defined, the probability for the harmonisation of the functionality of the "platform" and smart sensors functions and the communication parameters is relatively high, and the effective de facto standardisation of functionality, interfaces and communications choices may be expected.

Two aspects of smart sensors deserve mentioning here, even though they are not unique to the application domain. First, smart sensors for security require continuous sensor and actuator development based on a solid understanding of measurement and control for specific application domains. Second, smart sensors for security need to be designed to adapt to the environment in which they are used, in turn resulting in particular requirements for environmental conditions, energy management, communications, etc, in addition to the actual requirements for sensors (and actuators).

3.7.3 IMPACT

The market for security systems consists of a number of different sub-markets:

- Stand-alone security systems, such as metal, weapon and explosives detectors, and banknote verification machines
- Home security systems, covering consumer "do it yourself" markets to professional markets' small building/simple anti-intrusion systems, including motion sensors and remote functionality such as smartphone alerts
- Sophisticated building and private space security systems
- Security systems for public spaces[46]
- Security systems for complex applications – e.g., railway tracks and tunnels

In the literature, forecasts can be found that contain very substantial monetary volumes. As well as such estimates not always being realistic, it is important to realise that, although essential, the SSI part is only a small percentage of the total costs of the necessary infrastructure, installation and operation.

3.7.4 ROADMAP

In the following action items evolving from R&D, to demonstration and implementation, into industrial practice, are summarized illustrating selected high-priority topics on the timetable. The activity fields are similar to those listed in the application field Internet of Things.

ACTIVITY FIELD 1 Integrated security, privacy, trust and data protection solutions for smart systems

- Built-in hardware security features and access routines (bio-authentication features, encryption, protection from unauthorised access, remote updates and patches, etc)
- Integrated security and privacy principles by design for SSI applications

ACTIVITY FIELD 2 Standards, information models and interoperability for SSI

- Develop reference models and IT architecture for cross-sectoral technical modularisation/connectivity of smart systems, etc
- Information models for self-description – i.e. of data/measurement characteristics and intervention possibilities for semantic interoperability of smart systems

ACTIVITY FIELD 3 Integrated energy management approaches

- Wireless energy transmission concepts for short-range applications
- Develop low-cost miniaturised 360° energy concepts (storage concepts with batteries or super-caps, i.e. in combination with energy harvesting)

ACTIVITY FIELD 4 Security functionality and packaging

- Develop redundancy
- Develop resistance against physical and other attacks

46 *Reuven Harrison, 2015, "Smart Cities Need Smart Security Solutions", http://publictechnology.net/, March 30.*

For the roadmap on the SSI for security, the following milestones have been identified (see Figure 16):

Milestones 2020

Integrated security and data protection

Milestone 2025

Interoperable, horizontal and secure applications

Milestone 2030

Self-aware, autonomous and safe entities

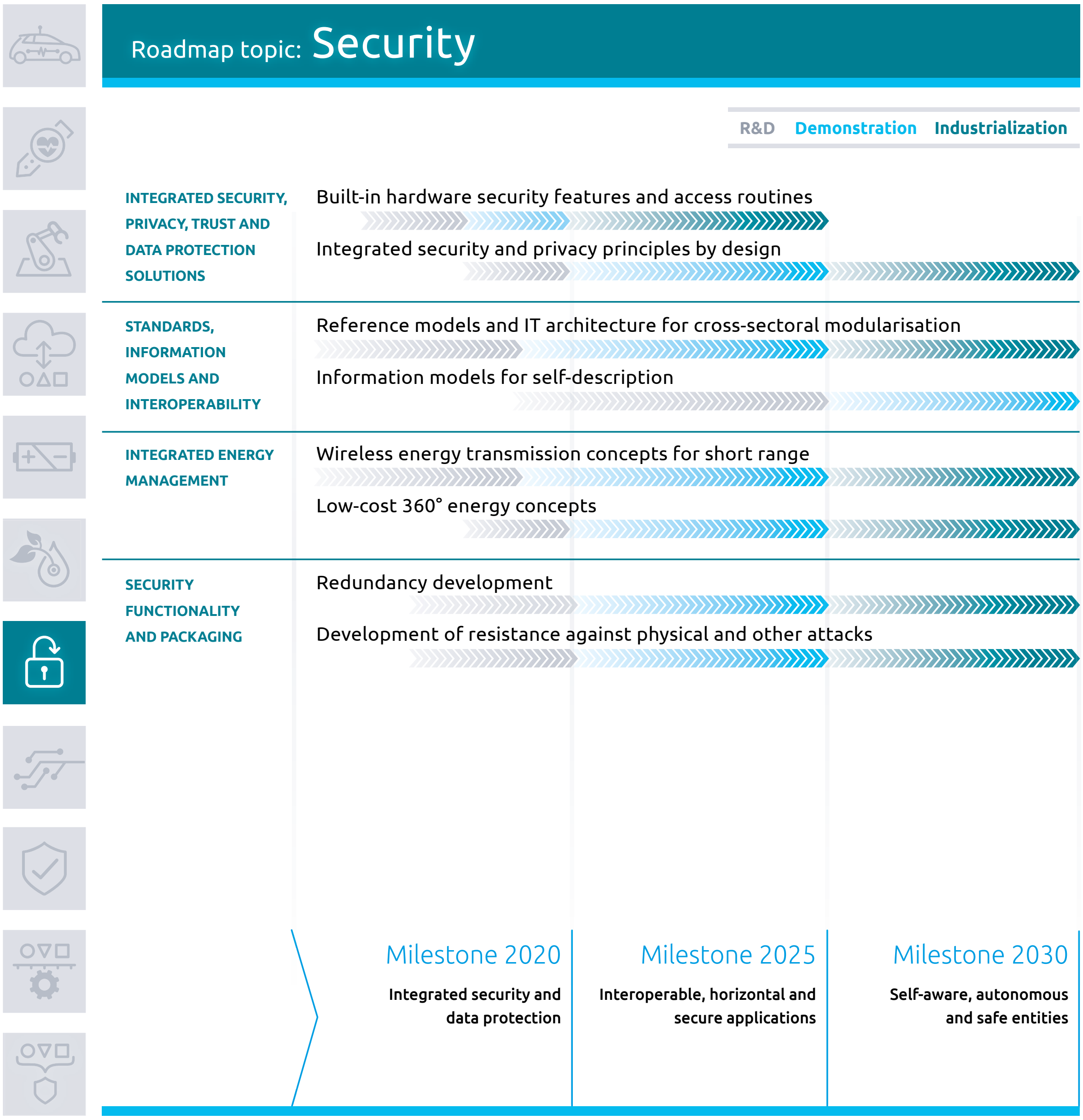


Figure 16: Roadmap for security

4

TRANSVERSAL TOPICS

4

TRANSVERSAL TOPICS

4.1

Technologies for smart systems

4.1.1 OBJECTIVES

Smart systems consist of components that interact both at the system level and with the outside world. Technologies for smart systems, as they are understood here, are fundamental to the properties and capabilities of these components and the system as a whole. They are highly diverse and address challenges at the interface between the physical, chemical, biological and engineering sciences. Although in practice they are often geared towards specific applications, technologies for smart systems are generic and comprise materials, building blocks and integration technologies, as well as implementations of system-level capabilities.

Although these application fields have very different requirements, the depicted systems benefit from the same transversal technologies. For example, compact systems such as advanced driver assistance systems and minimal invasive surgery devices require heterogeneous (3D) integration of different building blocks. Similarly, intraocular measurement devices and environmental sensors for dangerous substances both rely on wireless communication for data exchange. Finally, smart systems for collaborative environments, as well as driver assistance systems, require autonomous decision-making capabilities to enable efficient user interaction.

Future improvements and new developments in the technologies domain will target increased functionality, further miniaturisation and the cost-efficient manufacture of smart systems (see roadmap milestones).

4.1.2 STRATEGY

Today's smart systems combine nano-, micro- and power electronics with building blocks based on micro-electromechanical and other physical (e.g., electromagnetic, chemical and optical) as well as biological principles. They are able to monitor their environment, to transmit information to other systems and to take decisions towards further action.

Two main trends are placing new demands on technologies for smart systems.

- Technology pull: Emerging applications such as the large-scale implementation of the IoT require increased functionality as well as new building blocks and working principles.
- Societal need: Society desires high-end technologies on a large scale and at an affordable cost. Just as certain automotive sensors have become standard equipment, the automated car and devices in other application fields such as healthcare are likely to become popular in the future.

In both cases, there is a need to identify new designs, materials, testing, methods and tools to help towards the reliability, robustness, functional safety and security of smart systems. To meet these requirements, the time to market for subsequent products will be reduced by new designs, building blocks, testing and self-diagnosis strategies, methods and tools. Future materials, building blocks and integration technologies will need to be capable of meeting use-case requirements on reliability, robustness, functional safety and security in harsh and/or not trusted environments.

(Multi-)sensor and actuator-based devices will have to be capable of describing, diagnosing and qualifying their environment in a given complex situation, and to make predictions, come to decisions and take actions. The technologies will enable new applications based on their success in miniaturisation, heterogeneity, low power demand and in combination with the required reliability and safety. This includes materials and technologies for the formation of surfaces and interfaces between the individual components to guarantee the required interconnect functionality.

4.1.3 IMPACT

The smart systems sector in Europe represents nearly all relevant technologies and disciplines. With more than 6,000 such innovative companies in the EU, it employs approximately 800,000 people (as of 2012). Improvements in technologies for smart systems are expected to further strengthen European leadership in smart systems technologies and increase global market share.

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

4.1.4 ROADMAP

Technological advances have to be made in a great variety of technologies to enable future applications. Examples for the kind of technologies are shown in Table 2.

TECHNOLOGY	BRIEF DESCRIPTION	APPLICATION EXAMPLE
DESIGN AND SIMULATION	Whilst design and 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)
MNBS	Micro-nano-bio systems (MNBS) combine highly miniaturised engineering and computer technologies with biochemical processes.	Labcard™ diagnostic system (IK4-IKERLAN)
MEMS, MOEMS, MICROFLUIDICS	Micro-electromechanical systems (MEMS) extend silicon technology to include sensors and mechanical movement. Micro-opto-electro-mechanical systems (MOEMS) 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)
SEMI-CONDUCTORS AND 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)
MICRO-SENSORS, MICRO-ACTUATORS	Microsensors can, for example, miniaturise sensing to such an extent that body functions can be monitored internally without disturbance – i.e. 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)

TECHNOLOGY	BRIEF DESCRIPTION	APPLICATION EXAMPLE
COMBI-NATIONAL 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; and (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)
MULTI-FUNCTIONAL 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 HARVESTING, STORAGE & MANAGEMENT	Energy harvesting, storage and management technologies allow smart systems to make the most efficient use of energy and to gain their operating power from their surroundings when possible.	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)
PROCESS SENSORS	To save energy, materials and reproducible product quality in industrial process technology need in-situ multisensors, working under high temperature and harsh environment and with long term stability, higher sensitivity and selectivity with increased calibration interval or more in field calibration.	High stability pressure sensors (CiS)

Table 2: Examples of key technologies for smart systems

ACTIVITY FIELD 1 Sense and control

New mechanical, electrical, thermal, optical, chemical, biological and other actuation principles:

- Selective gas sensing
- Selective detection of allergens, residues in food/water, atmospheric particles, etc
- Disease monitoring & diagnostics (at home, POC, animal health)
- ADAS and autonomous car sensors
- First-level control with self-learning
- Second-level control with self-learning

ACTIVITY FIELD 2 Energy management and computing

Micro-power platforms, energy harvesting/storage/management, smart system autonomy, sensor intelligence, deep learning:

- Effective and reliable energy generation, scavenging and transfer
- 2D and 3D micro batteries and supercapacitors, including solid-state
- Smart power (mini-) modules for low-power sensing/actuation and efficient power transfer
- Sensor nodes with low-power & efficient computing architectures for real-time data processing

ACTIVITY FIELD 3 Materials

MEMS, MOEMS, microfluid, energy materials and power semiconductor processing technologies:

- Surface coatings for multi-functionality on the same base structures
- Highly miniaturised engineering and computer technologies with biochemical processes
- High energy density materials, high ZT thermoelectrics, (flex)piezoelectrics
- Materials for passives on chips and wide-band gap power electronics

ACTIVITY FIELD 4 Miniaturisation and integration

Integration and packaging technologies for miniaturised smart systems:

- Transfer printing of heterogeneous components on various substrates
- 3D printing technologies for heterogeneous system integration
- Heterogeneous integration of new materials, sensors, actuators for miniaturised chips
- Robust integration of multi-component smart systems on-chip and in-package

Concerning technologies of smart systems, R&D, implementation and industrialisation is a continuous process. Therefore, no milestones have been set (see Figure 17).

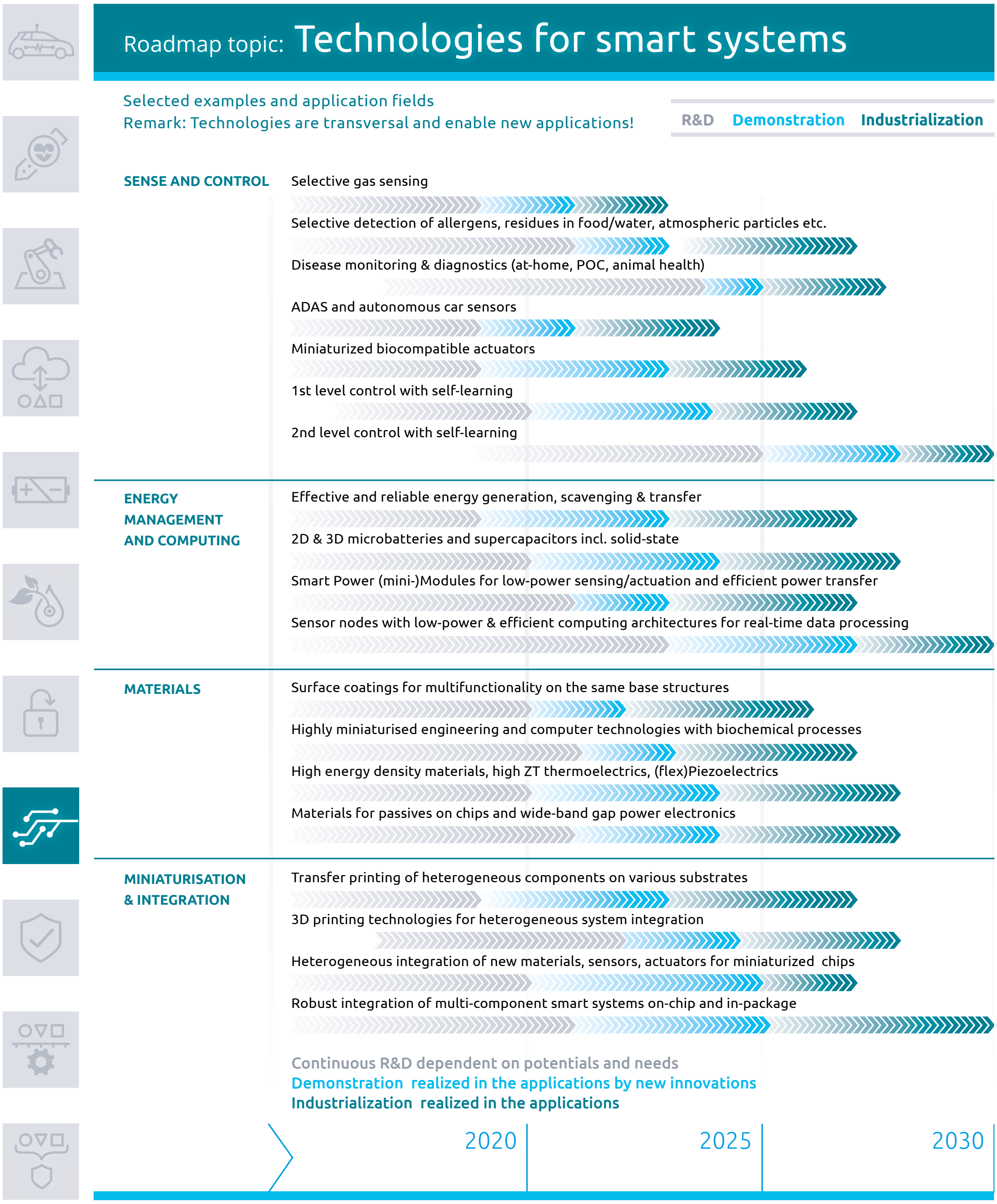


Figure 17: Roadmap for technologies for smart systems

4.2

Reliability and functional safety

4.2.1 OBJECTIVES

Below are some useful definitions in this area.

- Reliability: The ability or the probability, respectively, of a system or component to function as specified under stated conditions for a specified period of time
- Lifetime: The period of reliable operation (i.e. time to failure)
- Functional safety: The ability of a system or piece of equipment to control recognised hazards to achieve an acceptable level of risk – such as to maintain the required minimum of operation even in case of likely operator errors, hardware failures and environmental changes to prevent physical injuries or damages to the health of people, either directly or indirectly (through damage to property or the environment)

The objective of this transversal topic is to provide all means and methods needed for the new SSI solutions to meet reliability and functional safety targets (often referred to as safety targets only) with the first hardware realisation. This is despite the conditions as given by the following trends in SSI development, which actually increase the risks of early and wear-out failures, as well as worsening the severity of their consequences:[47]

- Continuous growth in number, complexity and diversity of the functional features generated, the components integrated, as well as technologies and materials involved in each product
- Increase in reliability and safety level to be achieved by the products, while simultaneously and more frequently being deployed to work in ever harsher environments
- Decrease in time-to-market and cost per product due to the increase in global competition
- Higher complexity in the supply chain by outsourcing raises the risk of hidden quality issues

In all SSI application fields, the development towards new functionalities and/or higher functional performance also has to account for the concerns of reliability and functional safety right from the start of the development/design process. This helps to avoid wrong decision that could otherwise lead to costly and time-consuming repetitions of several steps or even major parts of the design sequence. In the worst case, wrong design solutions can lead to unreliable products entering the market with dramatic consequences for the customers and the supplier. When shortcomings are detected, additional resources for the rework are often not available after the closure of the research project. Consequently, even promising functional research results end in a so-called "valley of death" – i.e. do not find their way into sellable products.

Therefore, this transversal topic has an important enabling role within SSI development. In particular, the research objectives on reliability and functional safety aim at:

- Determining the "physics of failure" (PoF) for all essential failure modes and interactions
- Fast technology and product qualification
- PoF-based DfX quantification schemes
- Methods and strategies for field data collection and prognostic health monitoring (PHM)

4.2.2 STRATEGY

The state of the art in reliability and safety methodology, as well as in the current assessment practice, demonstrate the following shortcomings and make it difficult to follow the trends in SSI development as listed in the objectives above.[48]

- PoF & qualification: Predefined qualification plans are applied based on standards but without rigorous adaption to the specific PoF situation, partly due to the lack of service/field data. Furthermore, these standards are based on old technologies and are not adapted to advanced SSI technologies.

47 *S.Rzepka, D. Andersson, B. Vandevelde, "Strategies for Responding to the Reliability Challenges of Future Smart Systems", International Conference and Exhibition on Smart Systems Integration 2014, Vienna, Austria;S. Rzepka, D. Andersson, B. Vandevelde, "Introduction to the EPoSS White Paper on Reliability of Smart Systems", European Expert Workshop on Reliability of Smart Systems, Fraunhofer Forum, Berlin, September 16–17, 2013.*

48 *ANSI/GEIA-STD-0009, "Reliability Program Standard for Systems Design, Development, and Manufacturing", August 2008;ANSI/GEIA-STD-0005-1, "Performance Standards for Aerospace and High Performance Electronic Systems Containing Lead-free Solder, Rev. A", 2012; Package Development Engineering, "Generic ASIC Package Level and Board Level Qualification Specification", AMD - GEN-CX0192-REV H, March 29, 2007; Barbara Jäger, "Robustness Validation for MEMS", ZVEI, Frankfurt, 2009.*

- DfX: While virtual schemes based on numerical simulation are widely used for functional design, they lack a systematic approach when used for reliability assessments. Individual approaches are used with limited comparability/portability, and hence lead to greater uncertainty about accepting simulation results or simulation-based findings from others. As a consequence, they cannot help to improve the qualification plans.
- Lifetime prediction: System-level lifetime predictions are still based on MIL standards (FIDES, Telcordia, etc) with constant failure rate statistics. Both infant mortality (i.e. early fails) and wear-out failures (forming the well-known bath-tub curve) are not considered, so lifetime prediction is highly imprecise – particularly in cases of new technologies and products.
- PHM: Some solutions on the application level have already become very popular (e.g., functional test of the airbag sensor at each vehicle start), but this is rarely the case for those on the component or system level except for high-end products (e.g., in avionics and energy infrastructure). The search for "key indicating parameters" remains at the basic research stage. Data security and various legal questions are also unresolved.

Consequently, the R&D&I challenges for reaching the above objectives are the following.[49]

- PoF: Identify and characterise the failure modes and mechanisms that will occur in new products, rank them according to their importance for the particular system and use-case scenario, and determine the actual root causes of the most important failures.
- Qualification: Develop new methods and tools for lifetime tests and physical failure analysis that cover the relevant service conditions comprehensively and with high efficiency; quantify the acceleration achieved by the tests, and prove the relevance of the failure mode/mechanism to the field use.
- DfX: Establish highly efficient and commonly accepted virtual schemes for all the essential risk phenomena based on calibrated models and validated simulations. These should be capable of predicting the reliability and safety performance of future products with the same accuracy (similar to experimental sample tests but in a much shorter timeframe). This allows lifetime prediction of PoF-based wear-out statistics instead of the FIDES-based constant failure rate.
- PHM: Develop effective and inexpensive monitoring structures and schemes for collecting service data from the field applications, identify key indicating parameters and deduce the methods for predicting the remaining useful life under the particular field conditions. It is also important to identify approaches to integration, and to apply the schemes and methods across supply chain hurdles.

4.2.3 IMPACT

Meeting the R&D&I challenges will impact developments in SSI as follows.

- PoF: A clear understanding of the physical root causes of degradation allows for the development of effective countermeasures, such as comprehensive failure avoidance strategies, damage and risk mitigation schemes leading to design solutions optimised for the respective use case, and active warning schemes for acting before the failure occurrence (e.g., maintenance, activation of passive redundancy features).
- Qualification: Efficient test and failure analysis methods with comprehensive coverage of the real service conditions based on PoF will shrink the time-to-market and boost the quality of the new products, which leads to substantial and sustainable advantages in terms of global competition.
- DfX: Validated virtual methods and schemes based on numerical simulations speed up the design process massively as they allow for replacing most of the time-consuming experimental tests up to the final qualification. They aim to provide "first time right" design solutions based on comprehensive case studies with much more legs than one could possibly afford in a merely experimental approach.
- PHM: The active warning schemes primarily provide the required level of functional safety. While they are mandatory for products in safety-related applications, they can improve customer satisfaction in any product – ultimately resulting in larger market success. In addition, PHM can also be used for scheduling maintenance precisely on demand, which allows the reliability to be improved massively with minimum engineering and logistics effort.

Innovative products can only be accepted by the customers and by public authorities if the reliability and safety requirements of the respective application field are fully met, in addition to offering new functional features. Therefore, this transversal topic is most essential for paving the way to the market for new SSI products. Moreover, reliability and safety are of concern, and have a great influence on customer satisfaction and trust. This means they can generate a positive attitude of easy acceptance that helps to unlock the potential of SSI technologies for creating products that benefit public health and the ecology while at the same time creating economic growth.

49 P.-E. Tegehall and G. Wetter, "Impact of Laminate Cracks Under Solder Pads on the Fatigue Lives of Ball grid Array Solder Joints", Microelectronics Reliability, 55(11), 2015, pp 2,354–70; Sven Rzepka, "Virtual Prototyping for Rapid Development of Smart System Technologies and Products", EPoSS Annual Forum, Lisbon, Portugal, October 8, 2010; Michael G. Pecht, Prognostics and Health Management of Electronics (Wiley), 2008; Florian Schindler-Saefkow et al, "Stress Chip Measurements for Process Characterization and Health Monitoring", EuroSimE 2012, art. no. 6191746.

4.2.4 ROADMAP

As shown below, the action items as foreseeable in each of the four activity fields are: PoF, qualification, DfX and PHM, respectively. The priority index shows the urgency of each action item in the respective SSI application field: mobility (M), energy (E), production (P), health (H) and society (S). The index takes into account the differences in system configuration, product volumes and use conditions, as well as reliability and safety requirements across these application fields. The timeline indicating R&D, demonstration and implementation phases, respectively, are strictly valid for the application fields with highest priority index (1). They are relaxed by a factor of about 1.5 for the fields of medium priority index (2). In the fields with lowest priority index (3), the action items are executed only after a first successful implementation of the methods in a field with higher priority – i.e. as an expansion of the scope of the methods that are already in use elsewhere.

ACTIVITY FIELD 1 **Experimental techniques – PoF analysis and assessment**

- Realistic material characterisation depending on process conditions, on ageing effects (e.g. solder, TIM, adhesives, housing) (M: 1, E: 1, P: 2, H: 2, S: 2)
- Physical failure analysis techniques (X-ray computer tomography, stress measurement) (M: 2, E: 2, P: 1, H: 2, S: 3)
- Comprehensive understanding of failure mechanisms, lifetime prediction models (M: 1, E: 1, P: 1, H: 1, S: 1)

ACTIVITY FIELD 2 **Experimental techniques – PoF testing**

- Integrated mission profile sensors in field products (M: 1, E: 2, P: 1, H: 2, S: 1)
- Wafer fab in-line and off-line tests for electronics, sensors, and actuators also covering effects such as CPI, heterogeneous 3D integration, packaging approaches for advanced nodes technologies (M: 3, E: 3, P: 3, H: 1, S: 1)
- Accelerated testing methods (e.g., high temperature, high power application) based on mission profiles and failure data (from field use and from tests) (M: 1, E: 1, P: 1, H: 3, S: 2)
- Multi-mode loading (TC+APC, TC+Vib) based on mission profile (M: 1, E: 2, P: 1, H: 3, S: 3)

ACTIVITY FIELD 3 **Modelling and simulation – DfX**

- Virtual testing – design of very harsh tests for component (and system) characterisation (to find the margin beyond the qualification level, i.e. the robustness) (M: 1, E: 2, P: 1, H: 2, S: 1)
- Mathematical reliability models also accounting for the interdependencies (e.g., found by simulation) between the hierarchy levels: device – component – system (M: 1, E: 1, P: 1, H: 2, S: 3)
- Mathematical modelling of competing and/or super-imposed failure modes (M: 1, E: 2, P: 1, H: 2, S: 3)
- Failure prevention and avoidance strategies based on hierarchical reliability approaches (M: 2, E: 1, P: 2, H: 2, S: 3)
- Parameter studies (automatic DoE assessments, material modelling, “what if” analyses) (M: 1, E: 2, P: 1, H: 2, S: 1)
- Virtual prototyping – DfR – building blocks (covering one effect after the other) (M: 1, E: 2, P: 1, H: 2, S: 2)
- Simulation methodologies and approaches (multi-scale, multi-field, …, reduced order modelling) (M: 1, E: 2, P: 1, H: 2, S: 3)

ACTIVITY FIELD 4 **Functional safety – PHM**

- Local data logger for recording the real and actual field conditions (environmental data, mission profile, ECS performance/degradation issues) with pre-treatment – on electronic system level --> cloud, data service) (M: 1, E: 1, P: 1, H: 2, S: 3)
- Monitoring test structures and/or monitor procedures (also: using available data) on component level for monitoring temperature, operating modes, parameter drifts, interconnect degradation – according to the failure Pareto plot (M: 1, E: 2, P: 1, H: 2, S: 3)
- Identification of “key indicating parameters” and prediction of “remaining useful life” (data collection, statistical assessment, prediction models) (M: 2, E: 2, P: 1, H: 1, S: 3)
- Huge sensor data management (find correlations, secure communication) and alarm management algorithms (M: 1, E: 2, P: 1, H: 1, S: 3)

Concerning reliability and functional safety of smart systems, R&D, implementation and industrialisation is a continuous process. Therefore, no milestones have been set (see Figure 18).

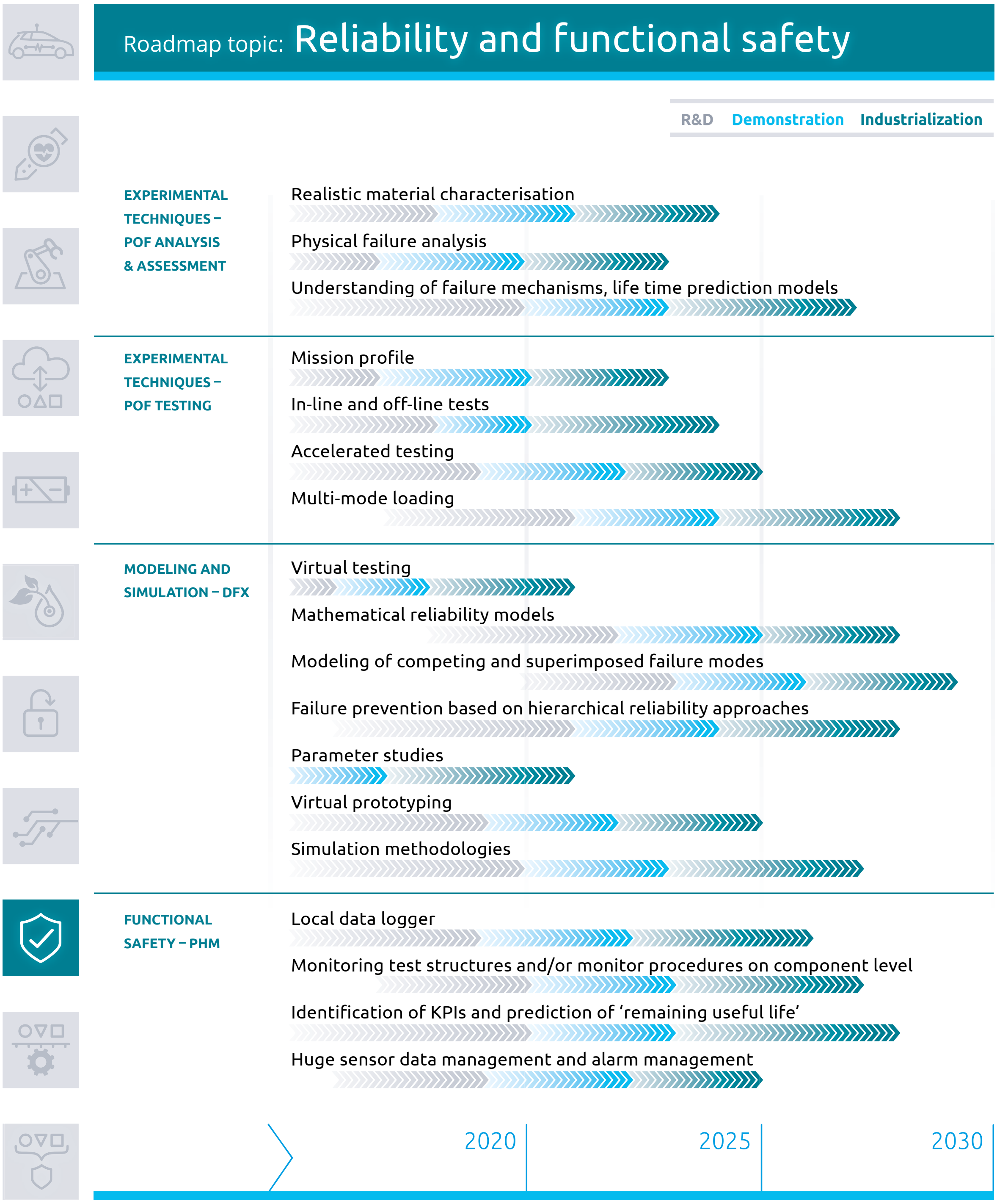


Figure 18: Roadmap for reliability and functional safety

4.3 Production processes for smart systems

4.3.1 OBJECTIVES

Per definition, smart systems consist of individual smart components that interact autonomously both at the system level and with their surroundings. They construct the system as a whole, allowing it to manifest some kind of “smartness” in numerous application fields: healthy living, automotive, communications, energy, water quality, smart textiles, forestry, food industry, and so on. On the one hand, smart systems help industries to facilitate a variety of production processes, and on the other they support humans as end-users towards better lives. Without wishing to sound presumptuous, this indicates clearly that the spectrum of application fields for smart systems is almost infinite. Likewise, the design of smart systems, their development and construction depend on a large number of parameters. These parameters can be categorised roughly as either *intrinsic* – i.e. concern the product itself, and includes materials, functionalities (including firmware), building blocks and standards, or *external* driving forces – such as users, trends, markets, connectivity, deliverers and environmental footprint.

The SSI industry produces a number of underlying smart technologies (components) such as sensors, actuators, semiconductor technologies, micro-nano-bio systems (MNBS), MEMS and LAE. After product design and subsequent testing, the orchestra of underlying process technologies leads finally to the integration of smart systems into smart products for enabling smart functionalities and services. The integrated smart system is a fusion of functionalities enabled by a set of materials, structural elements, parts or subsystems.

Components are versatile in sense of design (size, flexibility), material or composition, and thus the network of stakeholders involved in a production process of smart systems is equally complex (see Figure 19). If one keeps in mind that Europe’s supply chain towards smart systems production consists of more than 6,000 large companies and SMEs, new models for more efficient production processes that can react instantly to sudden market developments have to be developed.[50]

Looking at how the Internet, communications and the required technology has revolutionised the world in only the last 10 years, it is obvious that the short life-cycle of products or fabrication on demand are just a few of the issues to be concerned about. In addition, the demand for smart technologies regarding size, performance, quality, duration, energy efficiency to comply with data security and safety will increase as time goes on. Last, but not least, issues regarding materials (which range from polymer parts to rare earth metals), as well as their appropriate disposal, recycling, climate and environmental effects, will gain further importance and be regulated progressively.[51]

To overcome all eventualities, co-operation among stakeholders has to be tightened. Europe’s companies will also need innovative co-operation models due to the fact that smart devices can perform more than one single “smart task”. This trend will particularly target electronic devices in the consumer and health sectors, where the number of functions performed by smart systems will increase with time.

50 *M. McClellan, D. Riley and T. Sanford, 2016, “ Enhance Smart Manufacturing with Production Process Management”, Control Engineering, October 22.*

51 *H. Hirsch-Kreinsen, 2014, “Smart Production Systems: A New Type of Industrial Process Innovation”, conference paper, DRUI Summer Conference, June.*

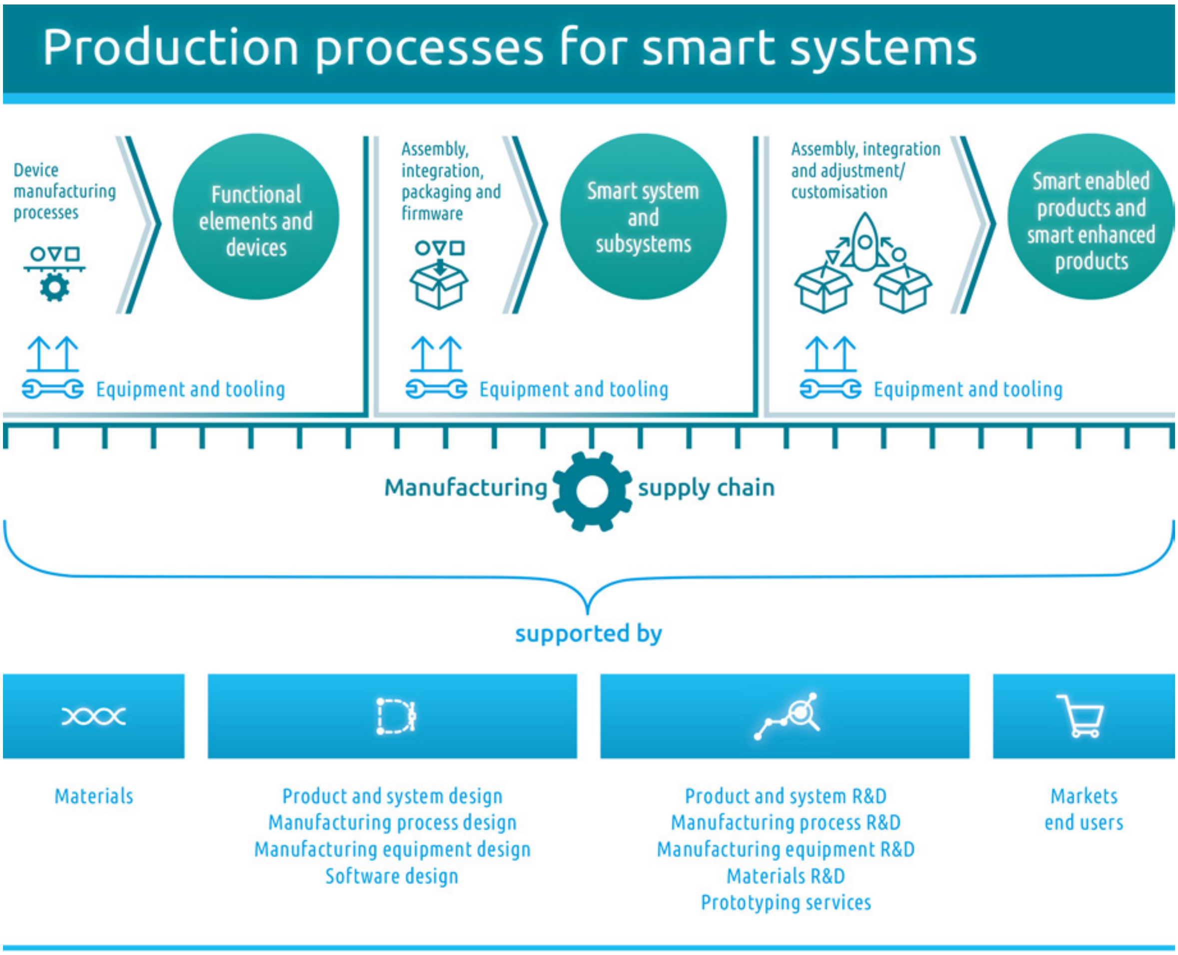


Figure 19: Production processes for smart systems do not focus on the manufacturing supply chain alone, but can depend on numerous intrinsic and external aspects

4.3.2 STRATEGY

The general strategic actions required are:

- Demand – individual manufacturing, personalised (medicine)
- Shortening the time-to-market – from research and testing through to production
- Automation of fabrication processes for smart devices
- Creating open-innovation platforms towards enabling easier co-operation of stakeholders
- Securing R&D&I financing towards SSI development in a complex ecosystem (regarding SMEs)
- Boosting efficient co-operation among stakeholders

The strategy for production processes that underpin and enhance smart system integration and implementation is based around a number of key technology areas.

- Etching and lithography: These techniques are the basis for systems on semiconductors, printed circuit boards and the tooling for many manufacturing processes. They involve subtractive patterning processes where material is extracted to leave a desired pattern.
- Printing and nano-imprinting: Such processes build up material in specific structures on a surface, and range from the deposition of material via screen printing and other printing techniques, as well as nano-imprinting involving the nano-scale combination of stamping with material deposition to produce fine surface features.
- Micromachining, forming and handling: These processes combine those essentially "mechanical" processes that can be applied to smart systems manufacturing. Machining and forming can often be applied to the manufacture of models, prototypes and small batches.
- Microjoining and bonding: These are processes that provide permanent bonds between parts at the micro-scale, such as welding, compression, laser, thermo-sonic, ultrasonic, radio frequency; brazing and soldering; adhesives; and anodic bonding.
- Moulding and micromoulding: Injection moulding, transfer moulding, overmoulding and vacuum moulding are process that are integral to the formation of thermoplastic and thermoset parts, resin and filled resin parts, glass parts and ceramic parts.
- Deposition and coating: These processes involve sputtering, electro deposition, spraying, plasma deposition, for example, while coating technologies can offer a broad range of functions for "smart surfaces", or the selective protection for sensors to avoid damage while allowing them to operate.
- Encapsulation: The purpose of this process is to define the product, and protect the product and user while still allowing it to work properly. Often, encapsulation resembles coatings in terms of functionality, with the main difference being that it provides its own structural integrity and does not rely upon a supporting structure.
- Direct manufacturing and rapid prototyping: This technology differs from typical mass-manufacture processes in that they are typically software driven, with no physical tooling. 3D printing and stereolithography are two example processes in this area, while others are emerging.
- Test and inspection: Smart systems, with their integrated structures and composite materials, pose issues in both test and inspection, and can also involve the validation of tooling, the calibration and control of manufacturing processes, and the characterisation of multi-parameter sensors and actuators.
- Repair and recycling: Regulations for the collection, recycling and disposal of technological products at the end of their useful life are well-established in the EU, particularly for electronic goods and cars (although disposal has overtaken repair and routine maintenance in this field).

4.3.3 IMPACT

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

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

4.3.4 ROADMAP

The roadmap (see Figure 20) lists the actions that are required for optimising the production process of smart systems with respect to their design, development and testing, and reflects lines of action to be addressed over the next 15 years by future research and development programmes to realise the objectives described here. The roadmap is oriented along five major axes, each aiming to close the loop between the above-formulated strategies for the production processes of smart systems. Along the activity fields, relevant action items that would contribute to the expected impact and boost the entire smart systems are provided.

ACTIVITY FIELD 1 Comprehensive design

- Key technology areas (printing, etching, coating, etc)
- Bio-mimicking (bio-hybrids, fluidics)
- Bio-sensors, remote sensing
- Integrated design

ACTIVITY FIELD 2 Integration and packaging

- Integrated design
- Monitoring tools (incl. tests and inspection)
- Co-operation and business models
- Direct manufacturing and rapid prototyping

ACTIVITY FIELD 3 Manufacturing

- Co-operation and business models
- Volume reduction
- Automation

ACTIVITY FIELD 4 New and alternative materials

- Organic and bio-compatible
- ICT for diverse resources monitoring
- Recycling and repair
- Rare earths replacement
- GaN versus SiC

ACTIVITY FIELD 5 Firmware

- GaN versus SiC
- Health management
- Perception techniques

Concerning production processes for smart systems, R&D, impleplementation and industrialisation is a continuous process. Therefore, no milestones have been set (see Figure 20).

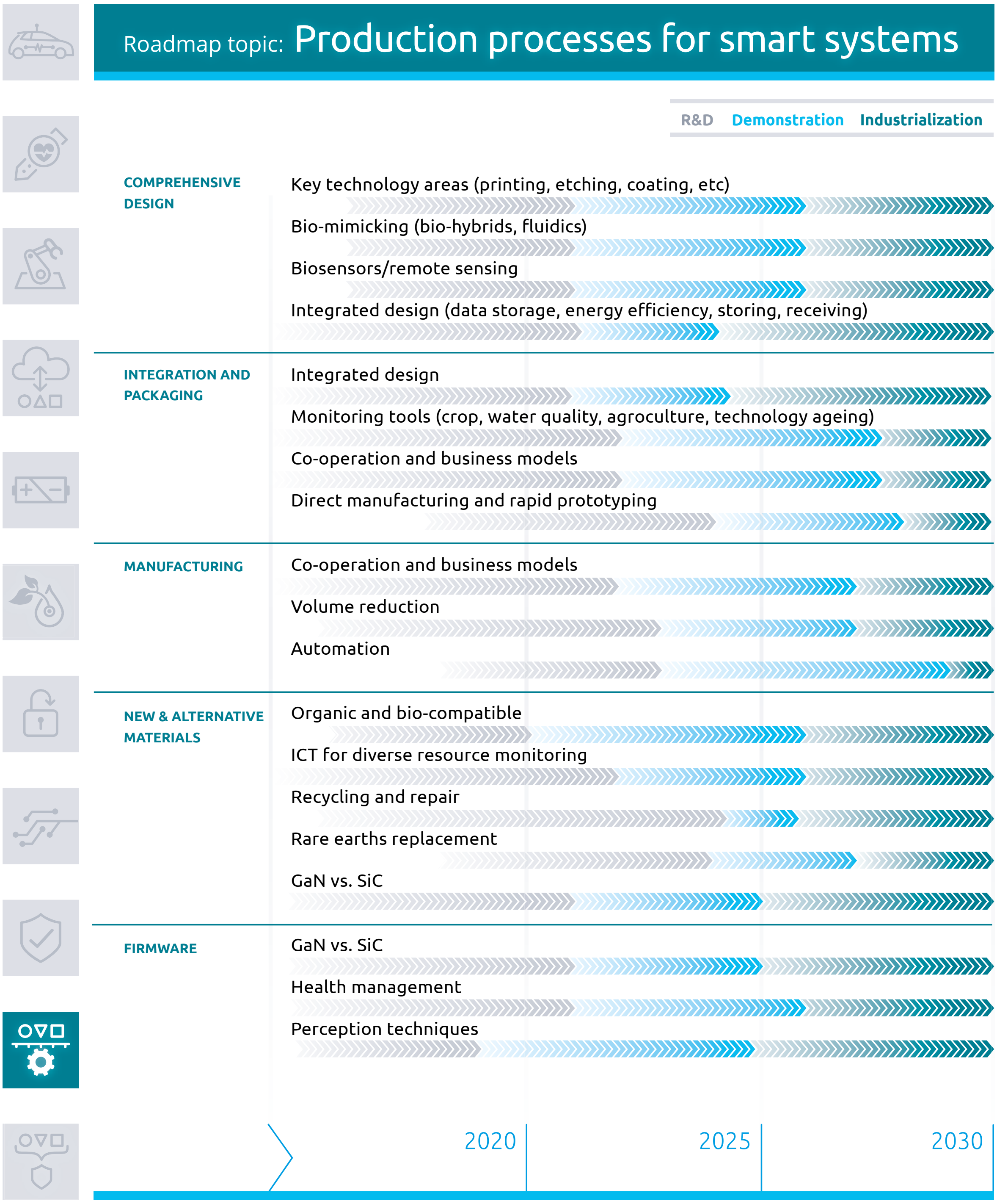


Figure 20: Roadmap for production processes of smart systems

4.4

Security of smart systems

Smart systems, as integrated with the natural, built and social environment, networks for power and data, other smart systems and the human, provoke a number of concerns over security. Enabling technologies are key to achieving the objectives of security and safety as transversal domains within the SSI paradigm, and which throw up a range of important societal and political issues. Strategy and effective measures need to be put in place to combat such threats.[52]

The security of smart systems is of utmost importance to allow them to operate despite accident or intrusion to ensure privacy and the security of individual items. Encryption and data security are seen as key here, indicative of the focus required in an increasingly connected and automated world. In addition, future smart systems could be more vulnerable to hackers than today's computers and smartphones, making it vital for authorities and governments to avoid such scenario. Cyber-attacks – any type of offensive manoeuvre by nation states, individuals, groups, or organisations that targets computer information systems, infrastructures, computer networks, and/or personal computer devices through malicious acts – can disrupt the integrity or authenticity of data, usually through code that alters the program logic that controls data, leading to errors in output.

4.4.1 OBJECTIVES

Security concerns are one of the main constraints to the widespread adoption of smart systems. If there is ability to manipulate physical assets remotely, then there is the danger of privacy violations and safety problems. Such issues can then, in turn, promulgate worries about security. It is hoped that regulation will also help alleviate some of these concerns, and thus be an enabler of smart system technology. Standardisation could also add a further layer of safety to security application, while industry alliances in terms of interconnected ecosystems could evolve into best practice for areas such as privacy, security and authentication, as well as establishing interoperability standards.

52 *F. Aloul, A. R. Al-Ali, R, Al-Dalky, M. Al-Mardini and W. El-Hajj, 2012, "Smart Grid Security: Threats, Vulnerabilities and Solutions", International Journal of Smart Grid and Clean Energy", 1(1), September.*

OBJECTIVE 1 SSI technology that underpins threat management

To support measures that work to overcome threats to people, the detection of and prevention against intrusion, unauthorised access, theft and falsification, and combating terrorist activities, it is important to develop safe and secure communication and networking technologies for seamless integration into the smart systems. They must face a number of technological challenges to offer fast, efficient, and fail-safe technologies for the wireless transfer of energy. These include the development of fast, energy efficient, fail-safe, reliable and secure wireless communication technologies and protocols for real-time data exchange.

OBJECTIVE 2 Enabling smart sensors to improve security

It is crucial, especially for SSI technology such as always-on sensor systems, whose design while being optimised at system level but adaptable to a range of architectures, must also be secure from external interference to ensure the application of security smart systems is optimised. Key enabling technologies for sensors, including electronic components and systems that integrate semiconductor chips running embedded software, should be developed in terms of functional safety, including fail safety of the system and fail operationality of the systems involved, something that can be helped through continually looking to improve design parameters. Smart sensors, for instance, need to also be based on enabling technologies that support applications for secure personal devices, assisted by obstruction technologies, sensor electronics and authentication technologies such as biometry.

OBJECTIVE 3 Increasing the resilience of smart systems

Infrastructures are attractive targets for hacking. Techniques for responding to cyber-attacks need to be implemented to establish, whether the attacks are based on malicious software such as viruses (self-replicating programs), worms (self-sustaining running program) or Trojan horses (designed to perform legitimate tasks but it also performs unknown and unwanted activity).

To mitigate such technology or cyber-attack emergency response teams are to be put in place to prioritise the dealing of attacks or vulnerabilities.

4.4.2 STRATEGY

It is inevitable to formulate key strategies that support intrusion-prevention and energy monitoring applications for smart systems. Here, R&D&I challenges are paramount. It will be important to put in place an infrastructure that ensures the full range of interested parties – technology companies, equipment manufacturers, service providers, end-to-end integrators, and security providers – to help ease concerns about the efficacy of the smart systems.

STRATEGY 1 Optimising technology for security and safety

It is vital that enabling technology underpins the work on all levels of smart systems. For instance, on the supply side cyber-security and cyber-physical systems consultancy, IT security advice and testing, can combine with specific applications to offer a wide range of secure systems.[53] In cyber-security, cyber-physical systems and smart mobility, transversal solutions need to take account of user business and societal needs using structured requirements analysis, and ensure that security is in place at all interfaces in the smart systems ecosystem, as well as being built into the architecture rather than just being added as an afterthought. Privacy needs also should be implemented through security and privacy by design. In addition, the security of mobile devices, applications and transactions can depend on smart embedded security for the smart system and digital identity and access management for cloud-based services. This can be reinforced through new designs, materials, testing, methods and tools that benefit reliability, robustness, functional safety and the inherent security of smart systems.

STRATEGY 2 Promulgating secure communication

Smart sensors for security and most other equipment for security applications must meet high standards in terms of secured communication and content, resistance to physical and other attacks and redundancy. While security system applications are being developed, more work needs to be done to achieve consistency and standardisation of functionality across technologies, especially in the area of communication. Smart sensors for security applications that focus on continuous sensor and actuator development need technology that helps them measure and control security aspects. They also need to be able to adapt to specific application environments and so transversally have a range of requirements for different communication needs, conditions and energy needs, to allow them to operate efficiently. This can be assisted by both widely deployed security mechanisms for smart objects, including techniques for issuing credentials, extensions that allow security protocols to be suitable for smart objects, implementing and deploying application layer security mechanisms and innovative implementations to ensure security protocols are a better fit for constrained devices. It is also important to effect the updating of variegated (and occasionally obscure) security protocols while ensuring both encrypted safety and reliability.

53 *A. S. Elmaghraby and M. M. Losavio, 2014, "Cyber Security Challenges in Smart Cities: Safety, Security and Privacy", 5(4), July, pp 491–97.*

4.4.3 IMPACT

In developing safe smart grid technologies – a combination of devices related to energy resources, distribution systems, smart metering, appliances, etc. – to upgrade the power grid with networked metrology and controls to improve efficiency and offer new ways to manage the system, such technologies provide new opportunities for cyber-attack on elements such as smart metering systems. Therefore, they must be designed to include input from cyber-security, reliability, fault tolerance design and systems engineering. As devices are developed by different vendors and have many layers of connections with a range of proprietary or open standard protocols for inter-communication, security procedures such as encryption or multiple levels of authentication are important.

Cyber-security also needs to have in place an effective system to control who has authorised access that can withstand sustained attacks from hackers, as well as system-wide resilience in its design and architecture, especially as one drawback of smart grid systems is increased vulnerability of the highly connected system and the knock-on ramifications on various related sub-systems and networks. Such connectivity brings associated dangers of exposed system entry points through nodes at various geographical locations, making it easier to be hacked.

The R&D&I challenges for achieving robust technology that helps to relieve threats through optimising technology and ensuring the efficacy of secure communication are important transversal areas. The separate sub-markets for applications discussed above highlight the importance of security to the SSI realm, and achieving this with the most optimal cost-effective approach. For instance, there are next generation autonomous smart systems that are expected to provide self-adapting, self-testing and self-healing properties, making technological solutions to threats to security and safety paramount, and this includes cyber-security solutions at all levels of the smart systems ecosystem.

4.4.4 ROADMAP

There are a number of key actions in R&D&I in enabling technologies for smart systems that will help achieve the objectives up to 2030. The roadmap on the security of smart systems focuses on integrated security and data protection, standards and reference models, functionality and sustainability in the short term, further demonstration of interoperable, horizontal and secure applications, integrated energy management, and security functioning and packaging in the mid-term, and greater design and implementation of privacy, trust and data protection issues, short-range wireless transmission concepts, designed sustainability models and security functionality, as well as self-aware entities recognising events and changes in their environment, and sensing and reacting autonomously in the long term. A transversal roadmap that is committed to enabling such technologies must include practically oriented research and development into all aspects of demonstration, as well as production and market for the timelines of 2020, 2025 and 2030.

ACTIVITY FIELD 1 Development of certification standards, design rules, testing and inspection methods to support integration technologies

These should help both safety and reliability, for instance, in terms of determining the physics of failure for all failure modes, enabling fast technology and product qualification.

ACTIVITY FIELD 2 Secure IT infrastructure

Transversal technology for security purposes should enable a host of infrastructure solutions. These include features such as tamper proof and smart reactive envelopes, smart security sensors and secure networking, secure computational and mathematical methods for real-time signal processing, data analysis, data fusion and data storage will also work to underpin an infrastructure purposed for security and safety.

ACTIVITY FIELD 3 Integration of hardware and software

Hardware and software manufacturers need to combine to improve the security of the open internet, and public and private sector systems. Some IoT devices lack the most basic cyber-security, allowing attacks that steal data, conduct espionage or cause physical damage. Poor security in such devices, including IP connected security systems, connected climate control and energy meters, smart video conferencing systems, connected printers, VoIP phones, smart fridges, and even smart lightbulbs, are a risk to the security of organisations.

ACTIVITY FIELD 4 Resilience

After a security vulnerability, affected code should be investigated and devices updated with patches to protect against similar incidents. This means that other users with the same equipment will be protected from similar attacks. Overcoming the risk of software vulnerabilities in a single category of smart devices posing a threat to the physical safety and the cyber-security of other networked devices.

To increase resilience and to fight potential threats, effective authentication and encryption measures must be implemented.

Concerning security of smart systems, R&D, implementation and industrialisation is a continuous process. Therefore, no milestones have been set (see Figure 21).

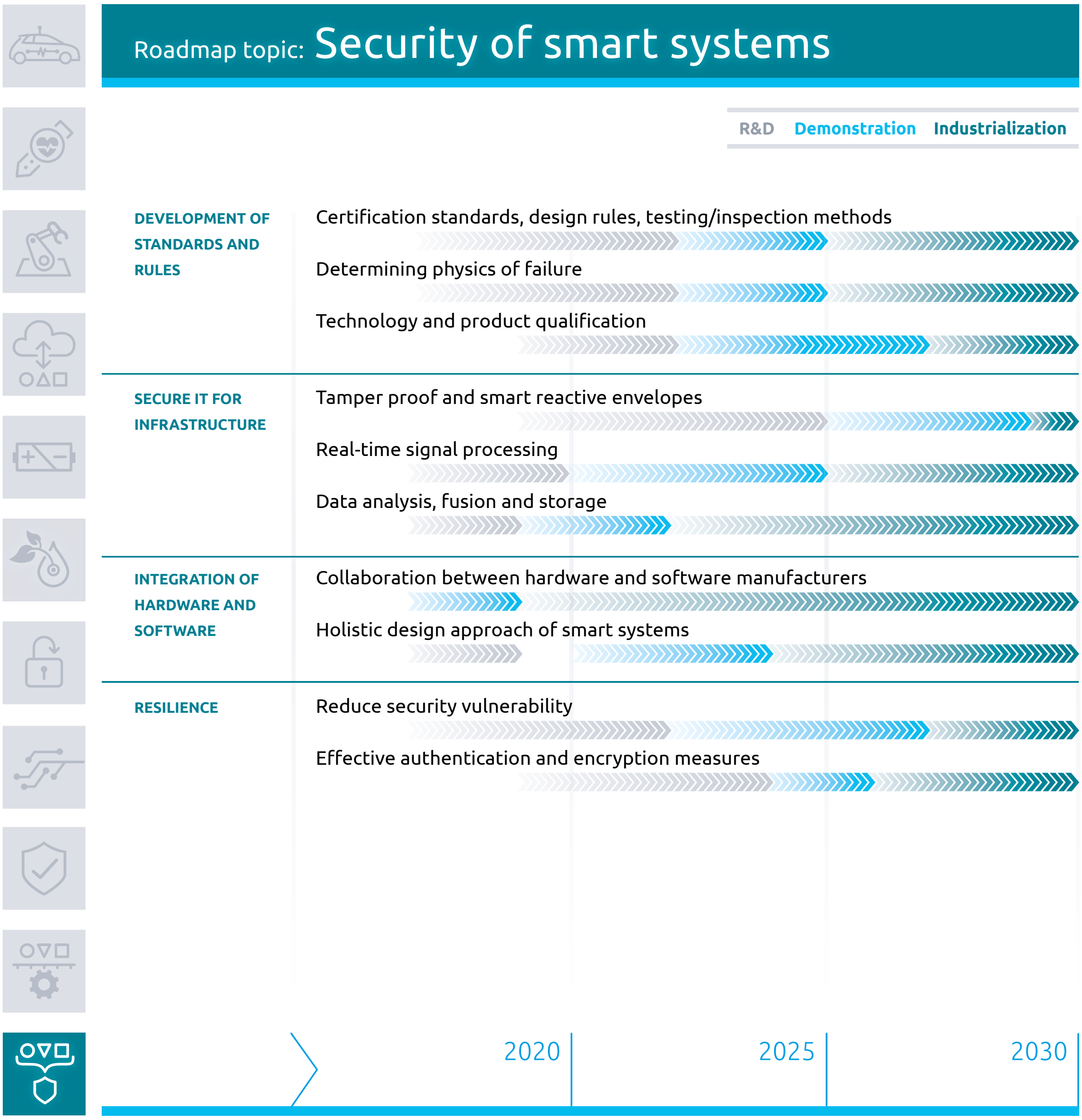


Figure 21: Roadmap for security of smart systems

Abbreviations

A	
A/D	Analogue/digital
ADAS	Advanced driver assistance system
B	
BEMS	Building energy management system
C	
CMOS	Complementary metal oxide semiconductor
D	
DBC	Direct bonded copper
DDS	Data distribution service
DfX	Design for excellence
E	
EDA	Electronic design automation
EIT	European Institute of Innovation & Technology
EM	Electromagnetic
ERP	Enterprise resource planning
ESTHER	Emerging and Strategic Technologies for Healthcare
ETPN	European Technology Platform for Nanomedicine
EU	European Union
EV	Electric vehicle
F	
FCEV	Fuel cell electric vehicle
G	
GaN	Gallium nitride
GHG	Greenhouse gas
GSM	Global System for Mobile
H	
HEMS	Home energy management system
HMI	Human-machine interface
HSM	Hardware security module
I	
ICE	Internal combustion engine
ICT	Information and communications technology
IMI	Innovative Medicines Initiative
IMS	Interconnection management system
IoT	Internet of things
ISM	Industrial, scientific and medical
IVD	In vitro diagnostic
K	
KET	Key enabling technology
M	
MEMS	Micro-electromechanical systems
MNBS	Micro-nano-bio system
N	
NVM	Non-volatile memory
O	
OEM	Original equipment manufacturer
OTA	Over-the-air
P	
PCB	Printed circuit board
PHM	Prognostic health monitoring
PoF	Physics of failure
PUF	Physically unclonable function
R	
R&D&I	Research, development and innovation
RDE	Real driving emission
RF	Radio frequency
RFID	Radio frequency identification
ROV	Remote controlled vehicle
S	
SET	Strategic Energy Technology
SiC	Silicon carbide
SME	Small- and medium-sized enterprise
SoA	Service-oriented application
SOC	State of charge
SOH	State of health
SPAD	Signal passed at danger
SRA	Strategic Research Agenda
SSI	Smart systems integration
SW	Software
T	
TOLAE	Thin, organic and large area electronics
TRL	Technology readiness level
V	
V2X	Vehicle-to-everything
W	
WLAN	Wireless local area network
WLTP	Worldwide light-duty test cycle

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