2017 Multi Annual Strategic Research and Innovation Agenda for ECSEL Joint Undertaking

ECSEL Joint Undertaking

Aeneas

MASRIA 2017
as prepared by the
ECSEL PMB

ARTEMIS Industry Association

EPoSS
European Technology Platform on Smart Systems Integration

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1. Introduction

This 2017 ECSEL Multi Annual Strategic Research and Innovation Agenda (MASRIA), on behalf of the ECSEL Private Members Board (PMB), serves as input/recommendation for the 2017 Multi-Annual Strategic Plan (MASP) of the ECSEL Joint Undertaking. This MASRIA describes* the Vision, Mission and Strategy of the ECSEL JU as well as the strategic research and innovation activities (in its Parts A and B) to be undertaken through the ECSEL Calls of coming years in order to enable the ECSEL JU to fulfil its objectives.

The MASRIA identifies and explores specific Electronic Components and Systems (ECS) technology solutions for smart applications relevant for societal challenges and industrial leadership in Europe. In order to maximise the impact of the programme, ECSEL JU will generally have its centre of gravity around larger projects, e.g., over 10 million euro, addressing higher Technology Readiness Levels (TRLs). However, this does not preclude smaller projects and/or projects addressing lower TRL's that focus on topics with strong industrial support. In this way, the ECSEL JU agenda complements other PPPs as well as generic actions within the overall Horizon 2020 program (see *Figure 1*, courtesy of the European Commission).

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* **N.B. Notice to the reader**

This MASRIA, being the view of the Private Members of the ECSEL Joint Undertaking, constitutes the first step in the creation of the ECSEL Multi Annual Strategic Plan (MASP) as a proposed text for the MASP. So rather than using the word "**describes"** the appropriate word would have been "**proposes".**

The construction of the MASP will be done by the ECSEL JU, subject to approval of the ECSEL Governing Board and based upon this MASRIA. In order to facilitate the ECSEL JU in this process, this MASRIA has been written in a form and style as if it were a MASP that is already endorsed by all members of the ECSEL Joint Undertaking. In this way a simple copy paste action is possible to produce the text of the MASP.

The reader that is interested in the MASP rather than the current MASRIA is advised to read the official MASP document as will be published on the ECSEL website.

In spite of the above mentioned form and style, this MASRIA should be considered as an input document to the MASP by the ECSEL Private Members.

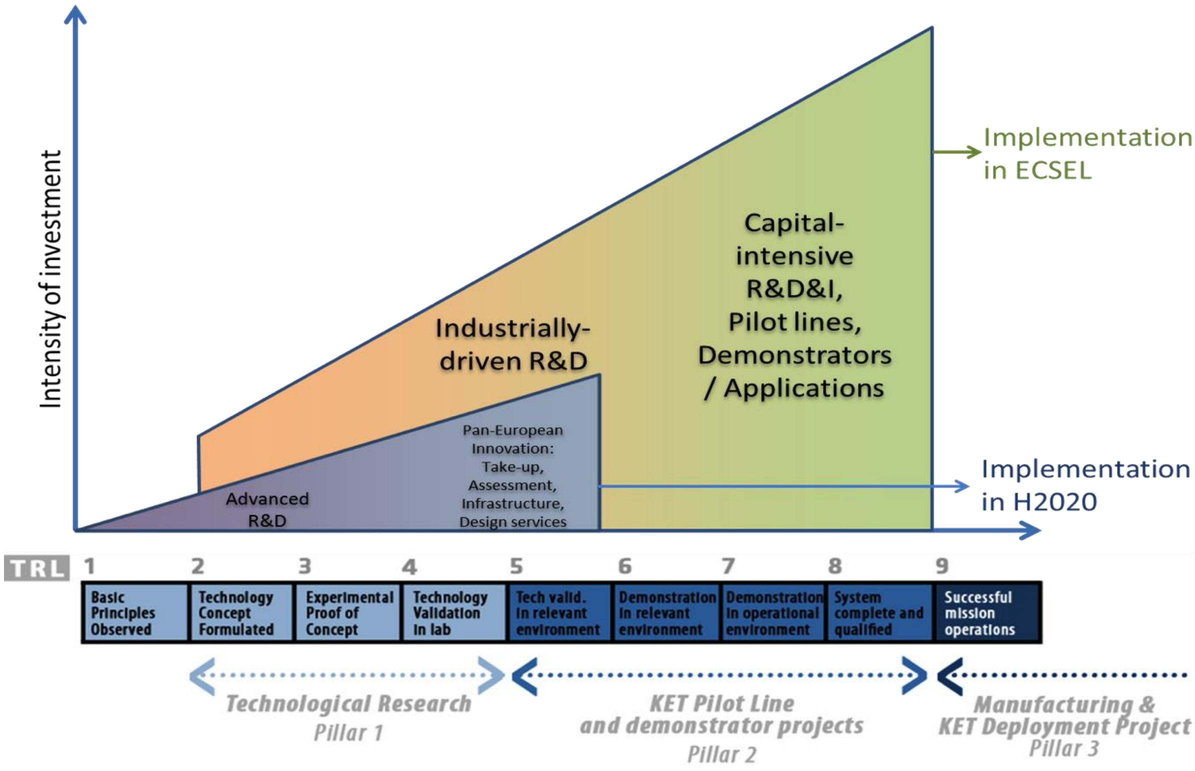

Figure 1: ECSEL JU and H2020 actions

The MASP, which is based on the MASRIA, provides the basis for the Work Plan of the ECSEL JU, where the selection of the activities and the type of actions to be initiated per year/Call is made in accordance with the funding budget(s) available.

1.1 Vision, mission and strategy

The European Electronics Components and Systems (ECS) industries and knowledge institutes share a common vision, mission and strategy at the highest level based on the Vision, Mission and Strategy as published in the High Level SRIA of the ICT Components and Systems Industries in 2012.[1]

The vision driving the ECS industries and knowledge institutes is one of mankind benefiting from a major evolution in intelligent systems, a world in which all systems, machines and objects become smart, exploit relevant information and services around them, communicate which each other, with the environment and with people, and manage their resources autonomously. Furthermore, the vision is to provide Europe, in a concerted approach, with the controlled access for creating the indispensable technology basis for the above as an essential element in a smart, sustainable and inclusive European 2020 society.

The mission of the ECS industries and knowledge institutes is to progress and remain at the forefront of state-of-the-art innovation in the development of highly reliable complex systems and their further miniaturisation and integration, while dramatically increasing functionalities and thus enabling solutions for societal needs.

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[1] High Level Strategic Research and Innovation Agenda of the ICT Components and Systems Industries as represented by AENEAS (ENIAC-ETP), ARTEMIS-IA (ARTEMIS-ETP) and EPoSS-ETP, April 2012.

The strategy of the ECS industries and knowledge institutes is based upon exploitation of European strengths and opportunities. Exploiting strengths implies building on the leading positions in specific capabilities, technologies and/or applications by increasing industry effectiveness and reducing fragmentation. Creating opportunities implies for Europe to be positioned at the forefront of new emerging markets with high potential growth rates and to become a world leader in these domains. Innovation is a key point for the strategy. It is propelled by efficient transnational ecosystems of industry, institutes, universities and public authorities.

In exploiting strengths and opportunities both supply of and demand for technologies need to be boosted simultaneously and in a balanced way. A strong supply base will make Europe competitive and it will ensure its controlled access to technologies essential for the implementation of the vision. On the other hand concerted and commercially viable contributions to a smart, sustainable and inclusive European society will create a strong European and global demand for these technologies.

Innovations are essential in all market segments where Europe is a recognized global leader or has the opportunity to become one. Stepping up R&D&I in ECS applications and technologies is a key enabler for sustainable European economic growth and wealth creation. For all these reasons, it is vital that judicious investments are made to assure Europe of access to ECS know-how and to industrial capacities to guarantee strategic independence in the face of increased globalisation.

Opportunities for large projects, exploiting our strengths in embedded software and systems know-how exist. Such projects exploit the opportunities offered by ECSEL in value chain integration and will lead to increased global demand for ECS related technologies. In particular ECSEL will develop further its lighthouse initiative, that fosters large scale projects of pan-European relevance, which are characterised by the need of a more intensive cooperation between the Public and the Private sector. Because of its governance structure, ECSEL is extremely well positioned to (co-)organise this type of projects. Lighthouse projects are not only targeted to solving societal challenges in Europe, but also to increase the export position of Europe in the Lighthouse domains, thereby increasing Europe's prosperity and employment opportunities. Preliminary studies and enquiries amongst Industry and Public Authorities confirm that all key applications mentioned in paragraph 2.2 could generate a lighthouse initiative.

The ECS domain is enabled by the key technologies micro/nano-electronics, embedded/cyber-physical systems, and smart/microsystems. In Europe, these technologies drive a value chain that employs over 9 million people including services[2] of which over 1 million direct and induced jobs in the semiconductor industry[3] .Together, they allow Europe to address a global market of more than 2,600 billion $ (see [2]) enabling the generation of at least 10% of GDP in the world (see [3]).

The ECSEL JU strategy endorses and supports the vision, mission and strategy of the ECS industries and knowledge institutes. In executing its strategy, ECSEL builds on the experience of successful European initiatives of the ENIAC JU, the ARTEMIS JU and the European Technology Platform (ETP) EPoSS addressing micro/nano-electronics, embedded/cyber-physical systems and smart/microsystems respectively. By consolidating these disciplines along the innovation and value creation chain, ECSEL offers a unique way forward to the next level of ECS know-how, for the best benefit of the European industries and citizens alike.

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[2] ITEA/ARTEMIS-IA High-Level Vision 2030, version 2013.
[3] A European Industrial Strategic Roadmap for Micro- and Nano-Electronic Components and Systems (Jan. 2014).

The ECSEL strategy includes the following essential features:

1) ECSEL is the instrument of preference for implementing the R&D&I aspects of the ELG strategy (see [3]). Furthermore it is an important instrument to realise the strategies as formulated by the ITEA/ARTEMIS-IA High Level Vision 2030 (see [2]), the AENEAS Strategic Agenda and the SRAs of the ARTEMIS-ETP and EPoSS-ETP.
2) The ECSEL actions will focus on European strengths and opportunities. Its innovation actions will continuously boost supply and demand in a balanced way. ECSEL enables here an accelerated innovation because the total ECS value chain is included.
3) ECSEL Lighthouses will address projects of common European interest where integration along the value chain is essential and where intensive Public Private cooperation is a condition for success. The projects in a Lighthouse initially consist of ECSEL projects; Lighthouses should however be augmented with relevant H2020 projects, Eureka projects and/or national/regional projects to form powerful clusters aiming for the same goals.
4) Whilst emphasizing large projects at higher TRL level, ECSEL will address industrially relevant projects of any size at TRL 2-8 by engaging the whole ecosystem, including large, medium and small enterprises, and knowledge institutes, from countries and regions both more and less developed.
5) ECSEL will pursue a defined agenda and complement it by mechanisms capable to update the overall strategy when necessary to respond swiftly to future societal evolutions and to enhance the global competitiveness of this fast moving industry. It will combine the dynamism and agility to respond to unexpected market developments of an open, “bottom-up” approach to participating R&D&I actors, with the rigour of a “top-down” defined, strategic framework approach connected with high-level societal and economic ambitions.

1.2 Objectives

The objectives of the ECSEL JU are listed in Article 2 of its basic act, paraphrased here:

1) Contribute to the implementation of Horizon 2020, and in particular to LEADERSHIP IN ENABLING AND INDUSTRIAL TECHNOLOGIES.

The objectives pursued by Horizon 2020 are summarized in the “REGULATION (EU) No 1291/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2013 establishing Horizon 2020 – the Framework Programme for Research and Innovation (2014-2020)”. Further details are in the “COUNCIL DECISION of 3 December 2013 establishing the specific programme implementing Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)” 2013/743/EU.

2) Contribute to the development of a strong and competitive ECS industry in the Union.

This ECSEL MASRIA is based upon inputs of many opinion leaders and experts from the member-organizations of the Private Members, representing the R&D actors in ECS at large, in all disciplines encompassed by the ECSEL JU. This MASRIA[4] and its annexes contain an overview of the societal/technical demand and trends, justifying the selection of topics and highlighting the

[4] The MASRIA is a document of the Private Members Board of the ECSEL JU, and published concurrently on their respective web-sites. See: www.aeneas-office.eu, www.artemis-ia.eu, www.smart-systems-integration.org.

requirements for the future in schedules and roadmaps. For background reading the AENEAS Strategic Agenda and the SRAs of the ARTEMIS-ETP and EPoSS-ETP can be consulted.[5]

3) Ensure the availability of ECS for key markets and for addressing societal challenges, aiming at keeping Europe at the forefront of the technology development, bridging the gap between research and exploitation, strengthening innovation capabilities and creating economic and employment growth in the Union.

The Regulation No 1291/2013 describes in detail the areas addressed by Horizon 2020, defining for each of them the specific objective, the rationale and the Union added value, as well as the specific actions to be taken. In addition, the Council Decision 2013/743/EU defined in detail the activities that shall implement the Regulation No 1291/2013, in particular with reference to the Leadership in Enabling and Industrial Technologies. The ECSEL JU MASRIA and MASP will rely upon these documents; it will make reference to concepts and actions put forward therein defining the specific topics to be addressed in its programme. For details regarding the rationale of the strategic choices, the reader is referred to the Regulation No 1291/2013 and the Council Decision 2013/743/EU.

4) Align strategies with Participating States to attract private investment and contribute to the effectiveness of public support by avoiding unnecessary duplication and fragmentation of efforts, and easing participation for actors involved in research and innovation.

The governance structure of the ECSEL JU involves the Public Authorities Board including the ECSEL Participating States to decide upon participation and public funding, and the Private Members Board drawing up the MASRIA, preparing the Research and Innovation Activities Plan (RIAP) and bringing the in-kind contribution. The progress of the engagements in the actions selected for funding is a direct measure of the alignment of strategies and procedures that shall bring together all actors, avoiding duplication and overcoming fragmentation.

5) Maintain and grow semiconductor and smart system manufacturing capability in Europe, including leadership in manufacturing equipment and materials processing.

Semiconductor technology, including materials, equipment and processing, is at the basis of ICT at large. The ECSEL JU shall use the Horizon 2020 instruments both R&D&I, to leverage the required investments to secure the sustainable controlled access to this technology for the European industry.

6) Secure and strengthen a commanding position in design and systems engineering including embedded technologies.

The value of modern semiconductor microchips or other miniaturised electronic components and embedded software is increased substantially when combined with system and integration know-how in the creation of cyber-physical and smart systems.

This is one of the synergetic benefits of ECSEL: linking ENIAC with ARTEMIS and EPoSS provides the essential link between large system design and requirements on chip level and vice versa, thus assuring the adherence to the required quality and safety standards by appropriate processes and tools along the value chain. Hardware and software are coming together, and the ECSEL actions

[5] The AENEAS Strategic Agenda and the Strategic Research Agendas (SRAs) of the ARTEMIS-ETP and EPoSS-ETP can be found on respectively aeneas-office.eu, artemis-ia.eu, www.smart-systems-integration.org.

shall strongly support both the advancement of the state of the art in each discipline and their concurrent application towards impactful applications.

7) Provide access for all stakeholders to a world-class infrastructure for the design, integration and manufacture of electronic components and embedded/cyber-physical and smart systems.

Microchips and embedded software can provide effective solutions to the societal challenges only if integrated in smart systems. Smart systems are here understood in the wider sense, extending the scope of ECS to include complex and large platforms. The ECSEL JU actions shall include projects that integrate the various ECS technologies described into systems that address the industry-defined applications included in this document.

8) Build a dynamic ecosystem involving Small and Medium-Sized Enterprises (SMEs), thereby strengthening existing clusters and nurturing the creation of new clusters in promising new areas.

The ECSEL JU shall continue the very successful activities of the Joint Undertakings established previously under the Framework Programme 7, engaging a large proportion SMEs within the winning ecosystem of the industry that also includes large industry and academic and institutional research institutions. Likewise, it shall continue creating opportunities to join powerful consortia for entities from all around Europe, with specific emphasis on SMEs from less developed regions, which shall thereby have opportunities to work together with the world leaders in the field, reducing differences and increasing cohesion.

1.3 Relationship with other programmes

The programme of the ECSEL JU is designed to provide valuable Key Enabling Technologies, components and competencies, as well as related know-how in design, manufacturing and implementation, allowing the community of R&D&I actors, alongside other existing programmes on ICT and related technologies in Europe, to benefit from new opportunities. Insofar, ECSEL is complementary to the other programmes.

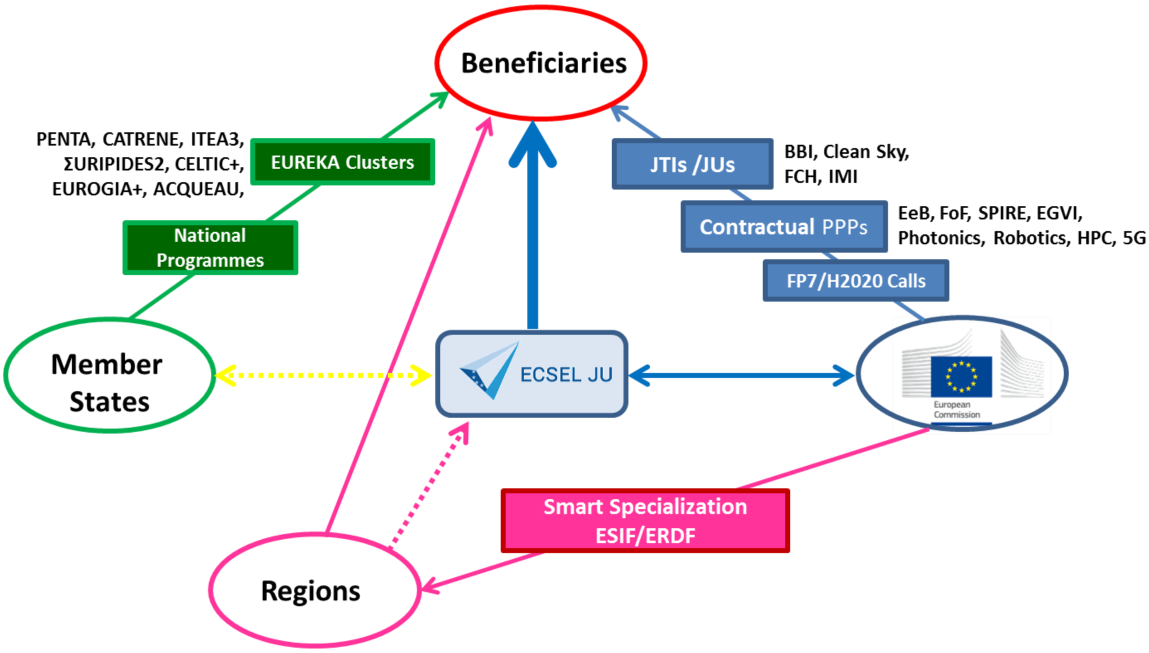

Figure 2: ECSEL JU - the Tri-partite Joint Undertaking: one Mechanism among Many

Regarding EUREKA clusters, and in particular with respect to PENTA and ITEA3, the policy of complementarity at project level and cooperation at programme definition level remains: One strategy – Two instruments. For EPoSS a constructive relation with Euripides can be mentioned.

As the EU part of the funding for ECSEL projects comes from the Horizon 2020 programme of the European Commission, the complementarity is particularly important and is assured as follows:

1) TRL and scale of activity: ECSEL envisages generally larger-scale, market-facing activities. While work at lower TRLs within larger projects is not excluded in ECSEL, the Horizon 2020 programme generally offers advantages for smaller, focussed projects on generally lower TRLs, and it is the expectation that the output of such Horizon 2020 projects will provide valuable inputs for further development towards market-readiness within the context of later ECSEL projects.

2) The H2020 facility for platform building provides for smaller CSAs or Innovation Actions. While the facility for CSA is foreseen in ECSEL, it is certainly not the focus of the programme, and the ECSEL community can make use, when appropriate, of platform building activities to form the mandatory seeds from which larger innovation ecosystems can grow.

3) “Networks of Design Centres” is an activity designed to promote the use of ECS in newly emerging or developing applications. It offers a funding flexibility conducive to experimentation, designed to trigger new market opportunities. Once these have been triggered, ECSEL (or other) provides a scheme much better adapted to further support the market-readiness of such new approaches on a larger scale. Such larger scale initiatives (“Pilot Lines”, “Innovation Pilots”, “Zones of full-scale testing” etc…) could also provide a means of access for SMEs and academia to leading-edge tools and infrastructures thereby contributing to the expected outcomes of the H2020 programme ICT2 and ICT25[6].

In addition, Article 7.1a of the Statues of the ECSEL Joint Undertaking takes provision to assure such complementarity by stipulating that: “*the Commission, within its role in the Governing Board, shall seek to ensure coordination between the activities of the ECSEL Joint Undertaking and the relevant activities of Horizon 2020 with a view to promoting synergies when identifying priorities covered by collaborative research.*”

[6] Horizon 2020 Work Programme 2015-2016: 5. “Leadership in enabling and industrial technologies: Information and Communication Technologies”, supplemented in future by the upcoming H2020 work programme for 2018 onwards.

2. Roadmap

2.1 High-level goals

Electronic components and systems (ECS) is a high-growth area, with a worldwide market growing faster than the industry average. European companies have dominant global positions in key application areas for Europe, such as transport, health and security, as well as in equipment and materials for worldwide semiconductor manufacturing. The technology domain is also very R&D intensive, with semiconductors industry investments reaching 20% of total revenues.[7]

Competitiveness of key European industrial domains heavily depends on the availability of leading edge ECS technologies, be it hardware and/or software. 80% to 90% of the key differentiating competitive features of e.g. leading edge medical device, automotive or avionic suppliers are dependent on the built-in Electronic Components and Systems with a strongly increasing importance of sensors and software. Therefore mastering these is decisive for the future market position of European strongholds.

Key companies and institutes in Europe's ECS ecosystem have proposed to invest up to 150 billion euro in R&D&I from 2013 to 2020, when leveraged by public and private co-investment programmes of up to 15 billion euro with the Union, the Participating States and the Regions (see [2, 7]). Objective of this holistic approach is to reinforce the ecosystem and have Europe expand its leading position and exploit new opportunities for products and services in this highly competitive domain. By 2020, this will increase Europe's world-wide revenues by over 200 billion euro per year (see [7]) and create up to 800,000 jobs in Europe's ECS enabled ecosystem (see [2]). Within this context and overall ambition, the semiconductor industry has accepted the challenging goal to double their economic value in Europe by 2020-2025 (see [3]).

The importance of software is demonstrated in a survey of the EU; it was revealed that the R&D investments by the European industry in software was 53.9 % of all R&D investments in 2015.[8]

Realisation of the above goals and objectives requires extensive collaboration across the innovation and value chain for ECS, with research institutes and academia, SME and large companies, and R&D&I actors from materials, equipment and microchips, together with design tools and architectures, to embedded and full-blown systems and applications in ECS. A two-proned approach will be needed, combining demand-pull and supply-push throughout the value chain. Within ECSEL the industry actors are together with the Public Authorities united behind a single European Strategy for ECS, thus making ECSEL the instrument of preference to realize the above.

2.2 Strategic Thrusts

The ECSEL JU will contribute to the above industrial ambition of value creation in Europe and the objectives in its basic act by establishing a programme through a two-dimensional matrix of key applications and essential technology capabilities, the ECSEL Strategic Thrusts.

These Thrusts support the European industry in the indicated top priority domains with key enabling elements (such as enabling technologies, components, processes and interconnected tool chains),

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[7] Nano-Electronics and beyond 2020: Innovation for the Future of Europe (Nov. 2012).
[8] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/2015-eu-survey-industrial-rd-investment-trends.

bringing them in a position to generate innovative products and services in very competitive markets. Part A and B of this document describe all these Thrusts respectively for key applications and essential technology capabilities.

Each Trust in part A and B is following the same structure:

- Objectives
- Strategy
- Impact
- Cross references
- Schedules and Roadmaps (NB these are indicative only!)

For each Thrust an optional annex is provided including additional information and a list of implementation examples. The intention of the examples is to provide a better explanation of the scope and content of the thrust at hand for potential project consortia and funding authorities.

In the MASRIA, the ECS community has identified opportunities for European leadership in existing and emerging markets that will create value and wealth for the European citizen at large. These Key Applications are strongly connected to the Societal Challenges identified under Horizon 2020, and can be summarized under the umbrella of 'Smart Everything Everywhere', riding the next Internet wave (i.e. Internet of Things [IoT]) by integrating networked electronic components and systems in any type of product, artefact or goods. The Key applications are enabled by Essential capabilities in technologies from each of the three ETP domains in the MASRIA.

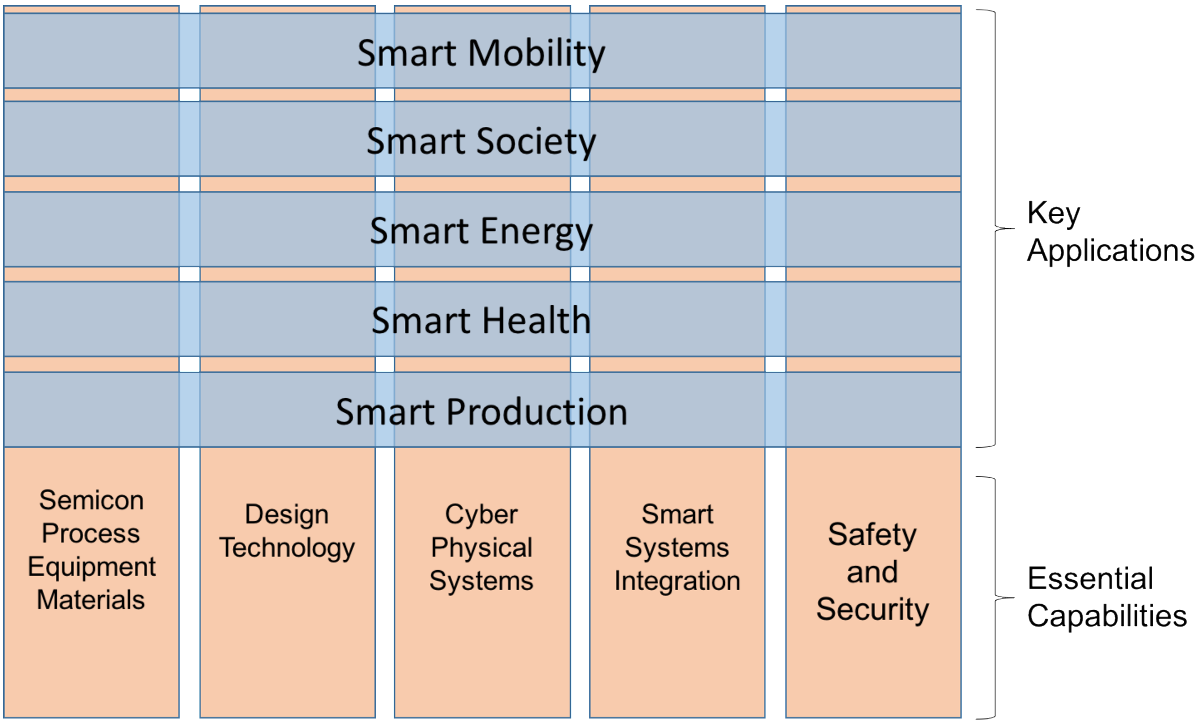

Figure 3: Structure of the ECSEL Applications/Capabilities domain arena

Figure 3 shows the resulting structure of intertwined and interdependent applications and technologies domains. This matrix approach maximizes effectiveness of the ECSEL programme by addressing the R&D&I activities along two axes, and maximizes impact by combining demand acceleration with strengthening of the supply chain. The Strategic Thrusts capture and summarize the high-level priorities of the Private Members; the full description of the technical challenges and the underpinning market analysis is available in the MASRIA. In addressing the major economic ambitions of the ECSEL program the dynamics of the ECS market do not allow the setting of additional a priori priorities within these high level priorities.

Projects of the ECSEL programme should not limit themselves to covering only one of these key applications or essential technology capabilities; on the contrary, multi/cross-capability projects will be encouraged wherever relevant. This cross-capability work leverages the presence of all actors along the value chain inside ECSEL. It is vital in creating initiatives of adequate critical mass and vital in fostering innovation that will contribute to the overall goals of ECSEL: for example they will be prevalent in Pilot Lines and Innovation Pilot Projects.

3. Making it happen

Because of comprehensive incentives outside Europe, the world is not a level playing field. Achieving the goals and objectives stated in the ‘Roadmap’ chapter of this MASRIA requires a holistic approach with multiple modalities for public-private co-investment. This chapter on ‘Making it Happen’ outlines the modalities in which the ECSEL JU can contribute, either directly through funded projects, or indirectly, as by informing and encouraging the partners in the JU.

The strategic Thrusts of the MASRIA define the key areas of activity for the ECSEL programme. The width and depth of the Strategic Thrusts’ subjects will ensure a broad participation of Participating States. Together, the identified activities encompass the complete lifecycle, from technology concept to system qualification, i.e., from TRL 2 to TRL 8 in terms of Technology Readiness Levels. On top of this the Strategic Thrusts encompass the complete value chain from design tools and materials to system-architectures and end-user products. For higher TRL’s, the model foreseen for execution in the ECSEL programme builds on the positive experience of developing Pilot Lines (in the ENIAC JU) and Innovation Pilot Projects (AIPP’s in ARTEMIS JU) respectively.

Standardization will drive the development of interoperable products/methods and tools addressing several fragmented markets. Large ecosystems will be created from the ECSEL projects sustaining European competitiveness. In the context of Innovation Pilot Projects reference platforms are foreseen that will lead to standardisation and interoperability while taking into account strategic standardization activities undertaken by the Private Sector.[9]

For consistency with the policy of open and transparent access to public funding, projects will be launched by the ECSEL JU through a process of open Calls for Proposals. For consistency with the annual budget cycles of the Union and of the participating states, at least one Call for Proposal per year shall be launched. To accommodate the broad range of TRL’s that must be addressed, multiple Calls per year are foreseen, handling lower and higher TRL’s in separate Calls. Each Call will identify its own budget and scope: the possibility of transferring unused National Contributions from the budget between Calls will be determined on a case-by-case basis.

SME’s are an important consideration when shaping new consortia and proposing projects. Fostering innovative SME’s is a cornerstone of the strategy given the importance of SME’s for the size and increase of employment in Europe in the ECS domain. Embedding them in eco-systems of large companies, RTO’s and academia, and giving them access to funds is a prerequisite for continuous growth. Within each project, a realistic representation should be found for the underlying R&D&I ecosystem in Europe, including large corporations, SME’s, institutes, and universities. The mechanisms to accommodate smaller partners, SME’s, institutes or universities in larger integrated projects shall be kept flexible, e.g., by allowing direct participation in the project, special links with one of the direct project partners, or a set of linked smaller projects. Being part of H2020, ECSEL aims to contribute towards the goal that SMEs will achieve 20% of the total combined budget for the specific object “LEIT” and the priority “Societal Challenges” (Regulation EU 1291/2013 establishing Horizon 2020, recital 35).

The ECSEL JU Work Plan (WP) will guide the content of the Calls in each year. Each Call can identify specific topics for projects (as described in the MASP that is derived from this MASRIA), and identify specific selection and evaluation (sub) criteria and weightings within the limits imposed

[9] As for instance specifically mentioned in the ARTEMIS SRA.

by the H2020 programme. In this way, the desired steering of the programme can be achieved within the principle of open and transparent selection of projects.

The following chapters describe a number of formats for projects that proposers may consider, for optimising the contribution of their projects to the strategic goals of ECSEL, and by extension to Horizon 2020. The types of project format available for each Call will be listed in the relevant Work Plan.

3.1 Research and Innovation Actions (RIA)

Research and Innovation Actions in ECSEL JU are R&D&I actions primarily consisting of activities aiming to establish new knowledge and/or to explore the feasibility of a new or improved technology, product, process, service or solution. For this purpose they may include basic and applied research, technology development and integration, testing and validation on a small-scale.

RIA projects are characterised as follows:

1) Executed by an industrial consortium including universities, institutes, SMEs and large companies, with at least three non-affiliated partners from three different Participating States;
2) Addressing lower TRL's (TRL 2 to 5);
3) Developing innovative technologies and/or using them in innovative ways;
4) Targeting demonstration of the innovative approach in a relevant product, service or capability, clearly addressing the applications relevant for societal challenges in relation with the ECSEL Strategic Thrusts;
5) Demonstrating value and potential in a realistic environment representative of the targeted application;
6) Having a deployment plan showing the valorisation for the ECS ecosystem and the contribution to ECSEL goals and objectives.

3.2 Innovation Actions (IA)

An IA project in the ECSEL JU is identified by:

1) Executed by an industrial consortium including universities, institutes, SMEs and large companies, with at least three non-affiliated partners from three different Participating States;
2) Addressing higher TRL's (TRL 4 to 8);
3) Using innovative technology;
4) Developing innovative solutions in relation with the ECSEL Strategic Thrusts;
5) Establishment of a new and realistic R&D&I environment connected with an industrial environment, such as a pilot line facility capable of manufacture or a zone of full-scale testing;
6) Product demonstrators in sufficient volume/scale to establish their value and potential;
7) Having a deployment plan leading to production/commercialisation in Europe.

3.2.1 Pilot lines and test beds

Pilot lines and test bed facilities focus on R&D&I actions requiring high levels of investment in bringing innovations to market. These activities are specifically relevant for micro and nano-electronics and comprise the work necessary to prepare innovation in the market with focus on validation and demonstration in relevant and operational environments to be established within the project. Also system completion and qualification must be part of the project focus. On the other hand, minor parts of the planned projects may need to address also lower TRLs in order to prepare the scientific and engineering ground for the pilot activities.[10]

3.2.2 Demonstrators, innovation pilot projects and zones of full-scale testing

Demonstrators, innovation pilot projects and zones of full-scale testing are essential building blocks in stepping up Europe's innovation capacity by the development of technologies and methodologies to support the integration of ECS applications and technologies into any type of end product, artefact or goods. This will provide Europe with reinforced means to significantly raise its competitive edge across the economy and to address its key societal challenges.

Innovation Pilot Projects are intended to transfer promising capabilities and results from lower TRL research activities into key application domains, allowing the well-known “valley of death” to be crossed. They are frequently the application-oriented counterpart of the more processing technology-oriented Pilot Line approach. These activities will foster and sustain the European innovation environment by creating new innovating eco-systems, by setting up and sharing of R&D&I infrastructures, by combining and leveraging R&D efforts to overcome the resource deficit for R&D&I in Europe, and by insuring successful valorisation and take-up of the results.[11] [12]

Zones of full scale testing of new and emerging discoveries in the ECS domain address the comprehensive investment in equipping and/or upgrading infrastructures for both the private and the public space, including homes, offices, transport systems, schools, hospitals, and factories. They require public-private partnerships involving the ICT supply chain and industries like engineering, energy, construction, health, tourism, and financial. ECSEL Innovation Pilot Projects can supplement the existing smart cities European Innovation Partnership and the Energy Efficient Building initiatives under Horizon 2020. They can also prepare for future large-scale innovative pre-commercial public procurement actions in the area of ‘Smart Everything Everywhere’.

3.3 Lighthouses

Lighthouses are ECSEL initiatives to support projects addressing strategic entrepreneurial and societal topics. Projects supported by national or regional funding, by Eureka, by H2020 or by ECSEL can become part of the Lighthouse. A Lighthouse advisory service will give support on invitation or on request to those projects who’s impact is dependent on the successful implementation of additional measures like legislation, standardisation, inclusion of other societal organisations etc. The advisory service will neither be involved in project selection nor in the management of individual projects.

ECSEL, being a tri-partite initiative, is optimally positioned to install advisory services for each Lighthouse. These services are formed by a high level and proper representation of the eco-system involved in the Lighthouse. Each advisory service will create a plan for implementing the Lighthouse goal, ensure sufficient attention for the Lighthouse on policy level, recommend adaptation of the ECSEL MASP and work plan, when needed, and help in the broadest sense to maximize the impact of the results of the projects contained in the Lighthouse.

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[10] As in the ENIAC Pilot Lines.
[11] As in the ARTEMIS Innovation Pilot Projects.
[12] This concept also embraces real-life experiments by systematic user co-creation approach integrating research and innovation processes in Living labs.

3.4 Multi-funding actions

Where the infrastructures required by Pilot Lines, Innovation Pilot Projects or other large-scale actions require significant additional investment, the incorporation of additional funding will be needed. Mechanisms for accessing such financing are already in place, such as the European Structural and Investment Funds, of which there are many with potential relevance to ECSEL R&D&I actions.

When preparing such large-scale actions through Multi-Funding, the following points must be addressed. Depending on the source of funding, the complexity of mixing funding streams from the Union remains problematic. To avoid this, the different elements of such multi-sourced action must be clearly identified, with exact description of the demarcation between them. A top-level Master Plan is essential for successful execution, including Intellectual Property Rights (IPR).

To be recognised as such, a Multi-Funding action must:

1) Build on at least one recognized ECSEL IAs, eventually complemented with other projects;
2) Provide a Master Plan that clearly identifies the demarcation of funding sources and IPR;
3) Provide clear tasks and demarcations for each funding source;
4) Provide for adequate risk management, should one of the components within the Master Plan fail.

3.5 Excellence and competence centres

Excellence and competence centres are important elements of the ECS ecosystem. In the context of 'Smart Everything Everywhere' solutions for the European Societal Challenges, they can be the coordination heart for business, industry and academic activities. Ideally, each will establish its own top class R&D&I capabilities, and will be charged with inclusion of other research centres within its region, and with coordination with the other excellence and competence centres, to form a virtual excellence centre to span Europe. To have impact, they will need to cover skills extending from chip design to embedded software, cyber-physical systems and systems integration, and offer easy access for low-tech or non-ICT industries wishing to embrace the opportunities that the momentum of the 'Smart Everything Everywhere' agenda provides. Financial support should come from Horizon 2020 as well as from national and regional R&D&I budgets including from the European Structural Funds.

3.6 Innovation support actions

To address the ECSEL objectives of aligning strategies with Participating States and building a dynamic ecosystem involving SMEs certain activities which are not directly related to R&D&I will be needed. Typical activities of such an action can include, but are not limited to:

1) Eco-system building support;
2) SME integration;
3) Roadmapping;
4) Standardisation;
5) Education / training actions;
6) Coordination of actions across European R&D&I programmes;
7) Planning and organisation of important dissemination events.

In part, such activities are on an in-kind basis by the Private Members. Funding through Horizon 2020 actions will be pursued.[13] [14]

[13] An example is the much needed development of a roadmap for specification and standardisation of More-than-Moore equipment and materials.
[14] Another example is the CSA CP-SETIS.

4. Financial perspectives

The funding made available by the European Union is projected to be 1.17 billion euro, which is to leverage **at least** an equal amount of funding to be provided by the ECSEL Participating States. This, when added to an in-kind contribution from the R&D actors of 2.34 billion euro, is expected to leverage a total investment approaching 5 billion euro for the whole programme.

5. Project selection and monitoring

This topic is not applicable for the MASRIA, however applicable in the MASP. It is mentioned here as a numbered section title to obtain consistent numbering for section titles as in the MASP that is derived from this document.

ECSEL JU Multi Annual Strategic Research and Innovation Agenda

Strategic thrusts

Part A: Key applications
Part B: Essential Technologies

Strategic thrusts Part A: Key applications

1 Smart Mobility

1.1 Objectives

The mobility sector faces **crucial societal challenges**: **reducing CO_2 emissions, improving air quality**, and **eliminating congestion** for improved logistics and traffic efficiency using existing infrastructure wherever possible while advancing towards an accident-free and causality-free mobility scenario, which also addresses the needs of **vulnerable road users** such as children or an **ageing population**. Predictive maintenance and smart service concept shall secure the **availability of the transportation infrastructure** at reasonable costs. In this context, Europe shall strive to **maintain global leadership** while serving the needs of society.

To solve above societal problems, the **Digitalization** of mobility requires enormous work in electronics and software is needed. This poses (sometimes disruptive) challenges for the European industry working on mobility, because classically it had its focus on mechanical engineering. Now **sensor technologies**, **embedded software** and **cyber-physical systems** as well as **powerful electronics** and **communication** systems in the vehicles, ships, airplanes as well as in the infrastructure systems, the electrification and the creation of **new business models** for mobility require a **transformation** of today's products and the companies.

The development and deployment of new capabilities provided by ECS (Electronics, Components and Systems) as well as the introduction of the necessary **new methods and tools** for the design, **verification & validation** and production are key to achieving this: ECS aims to provide vehicles[15], transportation systems and infrastructure with the required intelligence and flexibility by extending and reinforcing the well-established strengths of the European industry. An integrated approach between the different modes of transport is important. [16]

1.2 Strategy

In the framework of ECSEL, research, development and innovation in "Smart Mobility" will focus on capabilities in the domains of sensing, data acquisition and pre-processing, communication (within the vehicle, between vehicles and from vehicles to cloud based infrastructures), navigation/positioning, computing, prediction, decision-making, control and actuation based on ECS and the necessary development and validation tools and methods.

These functions will lead to **resource-efficient transportation** as they enable partly or fully electrified (including fuel cell based), as well as advanced conventional vehicles that are clean, CO_2-optimized and smartly connected to renewable energy sources.

ECS will also enable different levels of **partial**, **conditional, highly and fully automated transportation** posing new challenges to traffic safety and security in mixed scenarios where vehicles with different automation levels coexist with non-automated vehicles. Additionally, the target shall be to ensure flexibly coordinated logistics, mobility for the elderly, reduce congestion in cities, airspace, harbours, and further increase energy efficiency as it makes vehicles and traffic management systems smarter. New software technologies as big data analysis, deep learning or

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[15] In section "Smart Mobility" vehicle shall mean cars, airplanes, vessels, trains, off-road vehicles, light e-mobility satellites, drones.

[16] This is in-line with the goals of the Strategic Transport Research and Innovation Agenda (STRIA) under development in the European Commission.

autopoietic systems will be necessary, this will require innovative new development methods to ensure the safety and security which is imperative for transportation systems.

Finally, ECS will be fundamental for **integrated and multimodal mobility networks** based on smart vehicles and smart infrastructure (on and off roads, rails, in airspace and on waterways, stations, airports, hubs, etc.) and an increased level of information awareness (vehicle, route, weather conditions, etc.). Connecting cars to the Internet of Things (IoT) will lead to massive information exchange capabilities between mobile components and enable (entirely) new service possibilities, resulting in more comfortable and efficient travel and logistics. Thus, it also contributes to less congestion, increased safety and security, higher resource efficiency, faster point-to-point transfer, smooth intermodal shifts, and less pollution by the transportation system as a whole. Innovative security concepts will be substantial for the success of these functionalities. Integrated adaptability to new technologies in will be substantial to ensure long lifetime of the vehicles. ECS is also essential for promoting and extending the use of sustainable modes among users, including public transport (bus, metro, light rail, “last mile” transport, etc.), and “soft” transportation for “last-mile” transportation (eBikes, bicycle, pedestrians, etc.). Additionally, new mobility concepts as car-sharing need massive ECT support.

1.3 Impact

The innovation provided by ECSEL in Smart Mobility will help to shape the convergence of the worlds of digital data and transportation meeting the needs and capabilities specific to Europe and providing functionally safe and reliable products and related efficient processes. This will not only strengthen European leadership in electronics and smart embedded computer systems, but also supports Europe’s role as a frontrunner for innovation and engineering quality in the automotive and other transportation sectors, such as for instance aerospace and railways. Hence, it will help to strengthen those industrial sectors that are most important for employment and economic growth in Europe.

ECSEL is supporting and will take into account the activities of the European Green Vehicles, Initiative PPP and Joint Technology Initiatives as Clean Sky 2, Fuel Cells and Hydrogen 2, and specific parts of the three pillars of H2020, e.g. Mobility for Growth, Green Vehicle, Automated Road Transport, Smart Cities and Communities by advances in electronic components and systems for smart mobility. In doing so, ECSEL is helping to achieve the long-term objectives of the EC’s Transportation White Paper[17].

1.4 Cross references

Covering the step from basic functionalities to use cases in the value chain, ECSEL takes advantage of general technology research results from ICT and NANO Work Programmes of Horizon 2020 as CPS-based control, robots, IoT, cyber-security, big data, cloud infrastructures and services, MEMS-based (single or multi-) sensor technologies, high-performance real-time processors, power-electronics, highly reliable components, and qualification procedures etc.

This chapter “Smart Mobility” includes inputs from:

- European Roadmap for Electrification of Road Transport of ERTRAC and EPoSS (2016)
- European Roadmap for Automated Driving, EPoSS (2014)
- Draft EPoSS Strategic Research Agenda 2016
- AENEAS Agenda Automotive and Transport 2016

[17] White Paper Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system (COM/2011/0144 final).

- ARTEMIS Strategic Research Agenda 2016
- SafeTRANS Working Group “Highly automated Systems: Test, Safety, and Development Processes” Position Paper (2016)
- Some national research agendas
- Inputs from many members of the 3 industry associations from ECSEL

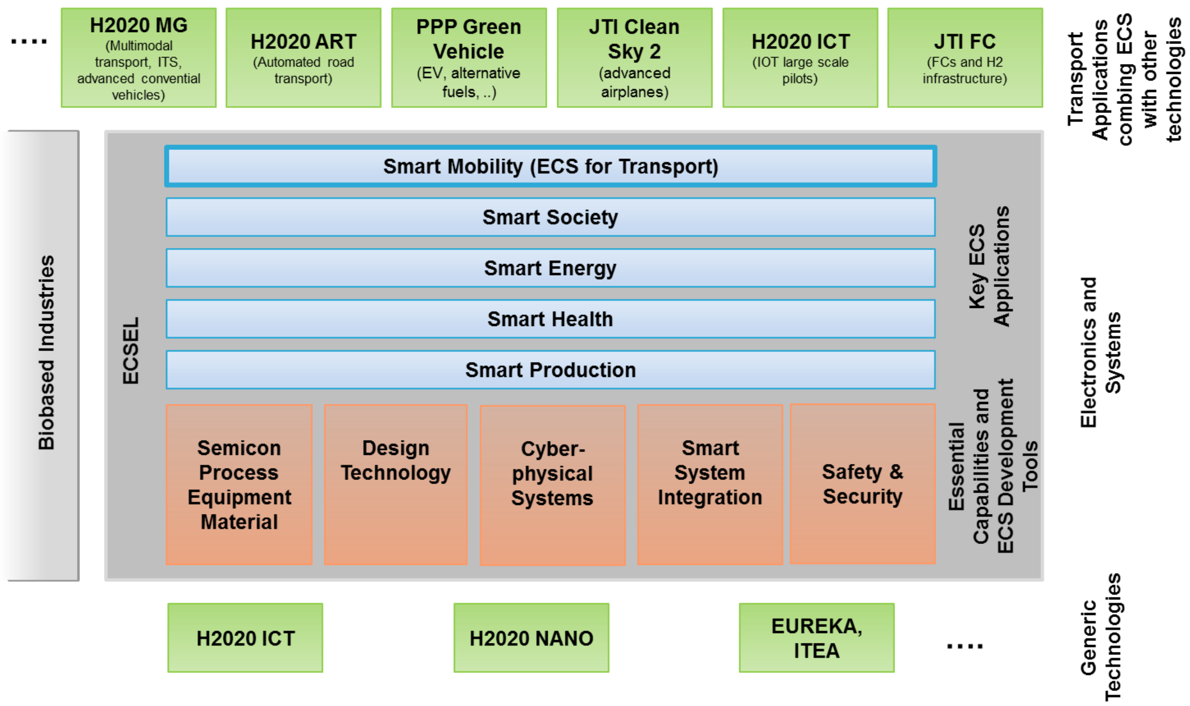

Figure 4: Relation of ECSEL Smart Mobility with other EU Research Programs

ECSEL delivers new revolutionary ECS functionality to application-oriented transport research programmes as H2020 -” Mobility for Growth”, H2020-“Automated Road Transport”, H2020-”Green Vehicle”, H2020-ICT-IOT Large scale Pilots (focusing on cloud infrastructure for intermodal and automated transport), JTI Fuel Cells and Hydrogen 2 and Clean Sky 2, where ECS results are combined with mechanical, chemical material and other application-oriented research to solve European transport problems. Synergies are also present between ECSEL and the H2020-“Space” Work Programme (e.g. in the navigation, communication and remote sensing domains), which contributes to the modern, efficient and user-friendly transport systems.

On the other hand, ECSEL continues to develop more advanced electronic components and systems including the underlying embedded software, and uses results of application oriented projects (e.g. automated vehicles, electric vehicles) as validation platforms. Therefore, interactions between ECSEL and application-oriented programmes will continue in future loops.

As ECSEL application domains take advantage of cross domain ECS technologies, the smart mobility research programme expects research results from horizontal ECSEL capabilities as semiconductor processes, equipment and material, design technologies, CPS technologies (as embedded systems design, development methods and tools, integration of real-time simulation with control, safety and security in CPS based smart systems) and smart system integration.

Safety & security is essential for smart mobility. **Connected and/or automated vehicles** as well as **intermodal transport** relies heavily on communication between vehicles and/or the infrastructure. As tempering this communication may even lead to fatal accidents, secure communication technology is of utmost importance. There are many more functions in smart mobility where security is key. Examples are convenience functions as keyless opening of cars, wireless sensors in cars, multimedia, software updates over the air, and many more. Safety is one of the key research areas in automated vehicles. Therefore, smart mobility is based on the results generated in the Essential Capabilities section “Safety & security”.

Other relations exist with the application areas “**Smart energy**” for example in using battery electric vehicles at charging stations to stabilize electrical grids. In future, even combined applications of smart health and smart mobility may exist, as sensors in vehicles may monitor vital functions of the passengers and provide the data in smart health applications. Privacy issues will play an important role.

1.5 Schedules/Roadmaps

1.5.1 Roadmap: ECS for resource efficient vehicles

The deployment of alternative resource efficient vehicles in Europe is expected to follow a series of milestones which link the market penetration to the availability and affordability of key technologies under the assumption of major breakthroughs (see also [18]). The milestones for cars are exemplary listed below:

1) By 2018 RDE compliant vehicles emitting less or equal to 95 g/km fleet average of CO_2 will contribute to the Paris goal to substantially reduce the global CO_2 emissions.
   - By 2020 a wider (mass) production of EV as well as medium scale production of FCEV shall be established in Europe; electrification will be transferred also to heavy duty vehicles. In addition, very efficient ICE (internal combustion engine based) vehicles will partially coexist or be largely transformed to hybrid concepts to achieve the European CO_2 reduction goals.
   - By 2025 the production of 3rd generation commodity priced EVs as well as (small) mass market FCEVs are foreseeable, and 15 Mio units accumulated will be on the road.
2) By 2030 transportation effort will be reduced by a convergence of the different mobility domains.

Europe will also see progress in bio fuel based vehicles. Similar roadmaps exist for other domains of mobility as rail, aerospace, off-road vehicles, trucks etc.

The advances needed to achieve these milestones are expressed through specific targets in the domains of sensors and actuators, energy storage, drive trains, vehicle system integration, smart grid integration, safety, integration into infrastructure (e.g. parking, charging, billing systems …) and transport system integration. **All of these features are enabled by ECS** as such vehicles will demand for **novel and increasingly powerful but more complex hardware, mixed-criticality embedded software and dependable vehicular networks**. Apart, electrical and thermal architectures and interfaces supporting intelligent charging and refuelling technologies are required. Overall, safety, security and transparent mobility services are a prerequisite for successful market penetration.

In parallel to the advancement of electric and plug-in hybrid passenger cars as well as light duty vehicle technologies, electrified trucks and buses or fuel cell vehicles will be developed. However,

[18] European Roadmap for Electrification of Road Transport, ERTRAC, EPoSS (2016).

the ramp-up of their deployment is expected to start later. Furthermore, resource efficiency is the driving force of research and innovation in other transport modes, e.g. air transport[19].

Additionally, the use of wireless sensors, actuators and interconnections for non-safety critical functions will help to save precious raw materials during the production of vehicles. On the road, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication in combination with new vehicle control algorithms will also contribute significantly to energy savings and safety in road transportation. Therefore, however, wireless vehicular networks will have to improve significantly and guarantee highly dependable communication for distributed and safety-critical applications in flexible transportation and tightly collaborating smart vehicles.

#	Topic \ Time (year of program call)	2017 - 2018	2019 - 2020	2021 - 2030
1. ECS enabled functions for resource efficient vehicles (airplanes, ships, trains, cars, …)				
Auomotive milestones	*M1.1: Market launch for 2nd generation EV and the first small scale deployment a FCEV (completed)*	*completed*		
	M1.2: RDE compliant vehicles(95 g/km)			
	M1.3: Mass production of passenger EV + medium scale production of FCEV + ICE vehicles transformed to hybrid concepts+ scaling up of heavy duty EV/FC applications			
	M1.4: Mass production of a 3rd generation commodity priced EV/FCs			
	M1.5: Combined automated and electrified vehicles			
	Filling/charging and energy management			
1.1.1	Energy management in vehicles			
1.1.2	Energy harvesting			
1.1.3	Inductive and bidirectional charging, fast charging, H2 filling			
1.1.4	Energy storage management (for batteries and fuel cells)			
1.1.5	Onroad charging			
	Control strategies and power interfaces			
1.2.1	Energy efficiency and CO2 and emissions control for all transport sectors			
1.2.2	Power electronics (form factors, efficiency, vehicle quality) for powertrains and auxiliaries			
1.2.3	Solutions for safety and reliability and security			
1.2.4	Development timereduction by multicriterial optimization of control unit parameters (using virtual experiment environments)			
1.2.5	Connected and automated powertrain to reduce energy consumption and emissions			
1.2.6	Convergence automotive and aerospace concepts			
1.2.7	Electric braking			
1.2.8	Sensors, instruments, tools for energy and environmental friendly mobility including big data (scenario) analysis			

Figure 5: Roadmap: ECS for resource efficient vehicles

1.5.2 Roadmap: partial, conditional, highly and fully automated transportation

Significant breakthroughs have recently been made in advanced driver assistance systems by European vehicle manufacturers and suppliers. In order to swiftly proceed towards highly automated driving and flying, where the system relieves the driver from steering, accelerating and

[19] Clean Sky 2 JTI Work Plan 2014-15.

monitoring of the vehicle environment, the following three steps can be foreseen in the automotive domain (see also [20] and [21], similar steps exists for the other domains in the mobility sector):

1) By 2020, conditional automated driving (SAE Level 3, see[22]) is expected to be available in low speed and less complex driving environments, e.g. in parking lots and in traffic jam situations on one-way motorways.
2) By 2025, conditional and highly automated driving (SAE Levels 3 and 4) is expected to be available at higher speeds in environments with limited complexity, e.g. on highways.
   - By 2030, (conditional and highly) automated driving is expected to be available in most complex traffic situations, i.e. in cities.

In closed and secured environments (e.g. factory floor, new city areas with dedicated infrastructure, precision farming, business and leisure parks, university campuses etc.), a revolutionary scenario to introduce highly or fully automated vehicles without too many intermediate steps is likely to be proposed first. While ECS therein will probably also be closed and carefully tailored, support for open environments will follow and impose much more critical demands: embedded hardware and software will have to be updated on a regular base to follow e.g. legal requirements, respect the latest standards, introduce new security aspects, services and features, ensure electromagnetic compatibility and to finally stay compatible with the latest vehicle technology.

Eventually, vehicles with different levels of automation will be built on advanced driver assistance systems and cooperating components as well as on detailed driver status monitoring and environmental perception. Such systems will have to be validated under virtual, semi-virtual and real world conditions. This requires ESC providing dependable solutions for advanced sensors and actuators, data and ontology fusion, efficient computation and connectivity, security, precise location, time and velocity detection, detailed scalable low cost and dynamically updated maps, precise lateral vehicle control, novel man-machine interfaces and human interaction technologies, cyber security, black box recorder for near incident data, energy efficiency and (real-time) simulation concepts.

To separate the development of sensors and actuators from control strategies and trajectory planning, a (de-facto)-standardization of object handling, object descriptions, scene interpretation, situation classification and management is essential. Therefore the creation of industrial frameworks is recommended and an exchange of test procedures between OEMs and suppliers is encouraged.

As it seems impossible to define all the safety relevant scenarios upfront, new “learning” concepts and adaptive lifecycle models are required, which continuously analyse real-world data for near incident scenarios, evaluate the potential impact, modify the control software or strategies, validate the improved systems and update all related vehicle components (maps, control software, information on road conditions etc.) in a highly dependable way, i.e., safe, secure, and in real-time over the air.

Traffic and fleet management systems are crucial for highly and fully automated systems. Dependable communication networks (enabled by terrestrial and space systems) with a wide coverage and high availability and data links among vehicles as well as between humans, vehicles and the infrastructure will be fundamental for traffic management systems. This will allow

[20] European Roadmap for Automated Driving, EPoSS, 2014.
[21] ERTRAC Roadmap for automated driving, 2015.
[22] Gereon Meyer, Sven Beiker (Editors); Road Vehicle Automation; page 11 ff; Springer 2014.

cooperative decision making in vehicle guidance and benefit from high performance computing systems (HPC).

Technology transfer to and from robotics and aeronautics and space is an essential part of the development process, and the creation of regulatory frameworks as well as in-vehicle and inter-vehicle standardization has to go hand in hand with technology development. Similarly, development of advanced and utilization of existing traffic infrastructure is mandatory to provide a frameset for automated transportation systems.

The development of smart & connected highly automated vehicles compared to conventional vehicles is by far more complex. Thus, new core elements for automation - as described below – and development and validation technologies are needed for these new vehicles. For example, it is not possible to test vehicles with automated features using conventional validation approaches only. It is simply not be possible to cover all possible street, track or air scenarios with these methods alone. Frontloading of testing activities, i.e. earlier testing is more needed than for the conventional vehicles. Model centric development and virtualization of testing by simulation is one technique to cope with the complexity. It shall cover:

- Architecture of automated vehicles as system as well as traffic systems
- Sensors and actors incl. their SW for real-time data acquisition management
- Handling of in-use big data in order to enable real-time decision making as well as learning SW cycles
- Development and standardization of common model of environment for system context modelling as well as test scenarios. An alignment between upcoming test centres and test areas for automated and connected vehicles across Europe is recommended
- Communication and transfer of relevant information between vehicles and between vehicles and infrastructure.
- Safety and security aspects, esp. for communication (inside and outside vehicle)
- Human interface aspects, human centric design, take-over between automated vehicle mode and manual driver mode
- Legal aspects

Over the air update using the knowledge derived from in-use data will be essential to cope with the extreme complexity of the driving environment e.g. cities.

The SAFETRANS workgroup proposes four such evolutionary stages of highly autonomous systems. Each such stage is characterized by distinguishing novel conceptual properties, inducing new challenges for system theory and architecture. These evolutionary stages are expected to overlap, rather than being available sequentially on the market:[23]

1. Functional automated systems handle limited, tasks in an exactly specified context, like parking or landing. The mission is planed offline or during development time. The system does not learn during operation and collaboration is restricted to the exchange of information about the system context.
2. Mission oriented systems fulfil a mission like highway pilot or area exploration. The system acts situational in a sequence of manageable, exactly specified situations and transitions between them. It optimizes its trajectories taking into account specified goals like time or other resources. The planning and optimization process is done during operation. The system does not learn

[23] Source: Safetrans Working Group Paper "Highly automated Systems: Test, Safety, and Development Processes" (2016).

during operation and collaboration with other systems is limited to the exchange of information about system context and the system itself.

3. Collaborative systems are able to collaborate with other systems on an intentional level to fulfil their mission (where ‘other systems’ here is meant to include humans) such as for collision avoidance and area surveillance, including swarm formation. They negotiate their goals, plans and actions with other systems and adapt their own behaviour to the negotiated plan. They exchange relevant context information. The system does not learn during operation.
4. Autopoietic systems go beyond self-learning systems in that they extend autonomously their perception, their situational representation and interpretation of the perceived world, their actions and their collaboration patterns, and are able to communicate such learned capabilities with other systems. This is close to human behaviour. The ability of (unsupervised) learning during operation is the major characteristic of this class of systems.

Figure 6 shows the detailed research topics and their planned roadmap in the ECSEL program.

#	Topic \ Time (year of program call)	2017 - 2018	2019 - 2020	2021 - 2030
	2. ECS enabled functions for partial, conditional, highly and fully automated transportation			
Auomotive milestones	*M2.4: Conditional automated driving in low speed and less complex driving environments, e.g. in parking lots and in traffic jam situations on one-way motorways.*			
	M2.5: Conditional automated driving at higher speeds in environments with limited complexity, e.g. highways.			
	M2.6: Highly automated driving in specific environments (e.g. taxis, busses, .)			
	M2.7 Highly automated driving in most complex traffic situations			
	Environment recognition and data distribution within vehicles (airplanes, ships, trains, cars)			
2.1.1	Sensors, actuators and sensor fusion – in- and outside of vehicle			
2.1.2	Positioning (including sensor fusion) including map updates/management over the air			
2.1.3	Scene and object recognition (including deep learning); driver health/emotion/intention recognition			
2.1.4	Traffic scene interpretation (also for different countries); scenario cataorization; catalogue of safety relevant scenarios; scenarion description language, system context modeling; tools and methods required for scene interpretation			
2.1.5	Methods to define fault (and/or degraded) behavior for exceptional situations in environment perception			
2.1.6	Lifetime, reliability, robustness; quality attributes of sensors; aging of sensors;influence of environment to sensor quality; handling of quality attributes of sensors in software; on-board diagnostics for automated transport systems, electromagnetic compatibility; redundancy concepts			
2.1.7	Harmonization of object lists, identifications, attributes, sensor protocols; open platforms for scenarios			
	Control strategies			
2.2.1	Framework for scene interpretation, environment object handling to separate sensing from control stategies; standardization of test procedures			
2.2.2	Service oriented distributed dynamically reconfigurable HW/SW architecture			
2.2.3	Mission oriented automated system sw: Mapping and routing, Control strategies & real time data processing; online mission verification; emergency control SW, fail operational strategies			
2.2.4	Technical goal oriented collaborative automated system sw: Mapping and routing, Control strategies & real time data processing; ADAS functions, ADV functions			
2.2.5	Ethical value oriented automated system sw			
2.2.6	Autopoietic control strategies for automated veicles			
2.2.7	Human-vehicle interaction; handover scenarios			
	Communication			
2.3.1	Safe and secure communication; build-in data security and privacy; cybersecurity for C2X			
2.3.2	Seamless integration and cooperation of multiple communication platforms : C2X, Radar, DAB, 5G, eLicense Plates, NFC, Bluetooth, 802.11p, etc.			
2.3.3	**Cloud backbone**			
2.3.4	Infrastructure supporting autonomous transport			
2.3.5	Intelligent in-vehicle networking (wire based and wireless)			
2.3.6	Use infield data to test new automated driving algorithms especially in safety or comfort critical situations			
2.3.7	SW improvement cycle using field data / big data analysis			
	Tools, Testing and dependability			
2.4.1	Sensor, actuator, communication test infrastructure and tools (including deep learning sensor algrithms)			
2.4.2	Test infrastructure and tools for automated and connected vehicle functions			
2.4.3	System test infrastructure and tools for automated and connected vehicles (including simulation models, co-simulation systems, test procedures, scenarios, stimuli for sensors, …)			
2.4.4	Training methods for automated driving functions (e.g. compare open loop ADV functions with manual driver reactions)			
2.4.5	Validation of fail operational concept for unknown envirionments; fail safe and secure operation			
2.4.6	Validation of autopoietic systems			
2.4.7	Evalution tools for safety and comfort of automated driving functions and system			
2.4.8	Functional safety and dependability			
2.4.9	Certification and testing			
2.4.10	Quality of services in extreme situations, e.g. EMC interference, disturbance by atmospheric radiation			
2.4.11	Scenario data base			
2.4.12	Alignment of testprodedures/scenarios/methods of testfields/labs for automated/connected driving; alignment of focus of testlabs to ensure cost effective usage of test infrastructure			
	Lifecycle			
2.5.1	Reliable and temper-free blackbox recorder for near incendent data (including dependable communication and near incident scenario evaluation, definition of minimal data set)			
2.5.2	Safe and secure over the air SW update			
2.5.3	Learning process for automated vehicles (including necessary online SW update-infrastructure)			
	Architectures, frameworks, developement tools			
2.6.1	Security, safety, privacy: architectures, methods, frameworks, tools on component level, vehicle level, infrastructure level; upgradeability			
2.6.2	ADAS/ADV frameworks (computer, HW, communication, SW, models, …) e.g. AUTOSAR			
2.6.3	Tools to develop components and systems for automated and connected vehicles : e.g. ADAS sensors, sensors and actuators for automated driving; communication networks, multimedia components			

Figure 6: ECS for partial, conditional, highly and fully automated transportation

1.5.3 Roadmap: ECS for integrated and multimodal mobility networks

The development path of **integrated and multimodal mobility networks** will build on achievements in the domains of vehicle technologies and travel information systems. Infrastructure development that is necessary for navigation, communication, information awareness systems and traffic management systems and interfaces between multiple modes of transport, intelligent booking, ticketing, tolling, and billing is important. This necessitates the development of both big data applications using high performance computing systems and deeply embedded systems using versatile hardware/software/communication to optimize these integrated and multimodal mobility networks (also open data or crowd sourcing concepts can be considered as well).

The following steps can be foreseen:

- By 2019, first implementations of integrated multimode mobility guidance system will be active.
- By 2030, todays different mobility domains of vehicles, trains or drones will converge into an integrated and harmonized mobility system.

This requires on the one hand significant research to establish affordable intermodal ECS-based infrastructures, and on the other hand research within the different modes to interact in an efficient and secure way (see also [24]). Specialized user interfaces and ways of communications for people with special requirements (as elderly or disabled persons or disabled citizens) need to be created.

Major milestones include the creation of an open common secure and trustworthy architecture for the interplay of all actors in all modes of transportation - whether public or private - in a comprehensive and intelligent system, the development and deployment of applicable vehicle technologies and services, and the standardization and harmonization of interfaces regarding **interoperability, efficiency, safety and security.**

These goals require intense work on highly dependable **multi-communication platform(s)** combining car to car or infrastructure (C2X) communication with e.g., 5G, Radar, DAB, eLicense Plates, NFC, Bluetooth, 802.11p or even novel protocols that are better prepared for immense network dynamics and traffic density. Considering personal mobility, vehicle routing, road-infrastructure and traffic management in combination with the deployment in different environments (e.g. cities or countries) or the establishment of a European Corridor and the alignment with other continents is crucial for a seamless integration and cooperation of multiple communication platforms. Special focus is also required to provide built-in security and privacy from component level to the overall system.

Vehicles and infrastructures will both benefit from advances in technologies (sensors, actuators, computing), positioning/navigation, timing, control and communication enabled by ECS. **Seamless integration and interaction** in a broad co-modal sense from road and energy infrastructure, traffic management to the individual types of transport from ships, trains, airplanes to cars, busses, trucks and off-road machines will be facilitated by significantly advanced connectivity in various forms and by the intelligent use of consumer electronics devices along with vehicle built-in technology.

Smart service concepts (e.g. predictive maintenance algorithms) will help the society to enjoy a ultra-reliable and highly flexible mobility system at reasonable costs.

[24] Embedded Cyber-Physical Systems ARTEMIS Major Challenges; 2014-2020, 2013 Addendum to the ARTEMIS SRA 2011.

#	Topic \ Time (year of program call)	2017 - 2018	2019 - 2020	2021 - 2030
3. ECS enabled functions for integrated and multimodal mobility networks				
Milestones	*M3.1: Integrated mulitmode mobility guidance system*			
	M3.2: Convergence of different mobility modes			
	Communication			
3.1.1	Cloudbased backbone services for multimodal mobility coordination			
3.1.2	Intelligent digital infrastructure and information systems for integrated and multimodal mobility (multiple environments as for example multiple countries, cities, …)			
3.1.3	Cost efficient secure wireless communication with vehicles			
3.1.4	Standardization of intermodal communication			
	Traffic management			
3.2.1	Traffic density control and (re)routing and cooperative decision making			
3.2.2	Multi modal, multi country traffic tolling and payment			
3.2.3	Trajectory generation and validation using HPC			
3.2.4	User interface to multi modal and integrated transport systems (including gamification algorithms)			
3.2.5	Online status/location monitoring and trajectory re-routing			
3.2.6	Intermodal cross country travel information			
3.2.7	Access and parking management			
3.2.8	IT systems for fleet management and car-sharing			
3.2.9	Rail energy use and storage management			
3.2.10	Aerospace SW platform for 100% operational availability and reliability, full situational awareness, human centered operation, seamless connectivity with the in-flight and ground environment			
3.2.11	Cost efficient, flexible reconfigurable, dependable and safely operating satellite systems for Smart Environment developments			
3.2.12	Swarm intelligence for traffic management (e.g. drones, containers,. …)			
	Guidance systems			
3.3.1	Predictive online traffic information (using social media and historic information from big data)			
3.3.2	Assistive transport networks systems (e.g. for the elderly living)			
3.3.3	Intermodal traffic guidance with personalized user interfaces and personalized way of interaction for people with special interestes (e.g. elderly people, handicapped people)			
	Smart service for mobility			
3.4.1	Smart service infrastructure			
3.4.2	Predictive maintenance systems in mobility systems			
3.4.3	Smart service for car-sharing systems			

Figure 7: ECS for integrated and multimodal mobility networks

2 Smart Society

In this chapter several aspects are covered of the “Smart Society” which consists of a multitude of sub-domains, such as Smart Grid, Smart Factory, Smart Building, Smart Home and Smart Car. The advent of ever more fast information gathering, exchange and processing will be the backbone of the smart digital society that aim to satisfy the demands for liveable (urban) environments with adequate mobility, energy, security, safety, food and water supply, etc. This implies business opportunities for Europe linked to various application areas: Smart Health, Smart Home, Smart Grid, Smart Cities, Smart Mobility, Smart Manufacturing and Logistics.

2.1 Objectives

Europe is in the middle of a changing world: More and more people living in urban environments pose major challenges like individual mobility, efficient energy consumption and distribution, security, safety, smart administration, food and water supply, logistics, entertainment etc. Intelligent, secure and easy-to-use solutions are needed to satisfy those demands in a sustainable way, guaranteeing citizen privacy and reaching broad acceptance in the public (for both urban and rural environments).

In this area, business opportunities for Europe will be supported by an integration of new technology trends such as big data analysis, machine to machine interactions, multi-functional mobile devices, and autonomous systems. The vision of a dramatic increase in use of connected sensors (illustrated below) is an important key element in these trends.

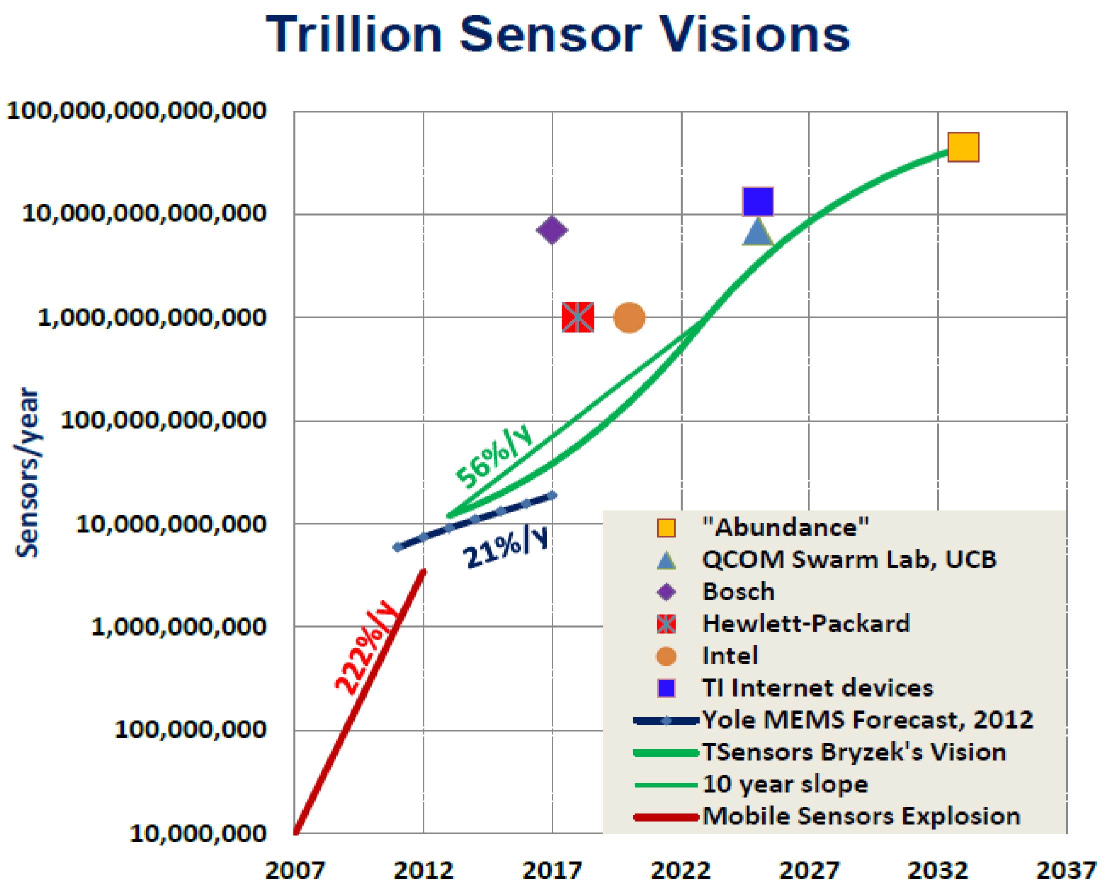

Figure 8: After J.Bryzek, Semicon 2013, San Francisco. Dramatic increase of use of sensors connected within IoT networks expected within next years will dramatically change life of societies, creating opportunities and threats.

Fast information exchanges between people, objects and machines in real-time, as well as efficient processing of this information will be the backbone of the smart digital society (illustrated below), hence a necessary, but not a sufficient contribution to such solutions. This “Smart society” chapter of ECSEL addresses this gap, while ensuring to keep pace with global technology trends and developments while aiming to offer reliable and valuable services for users.

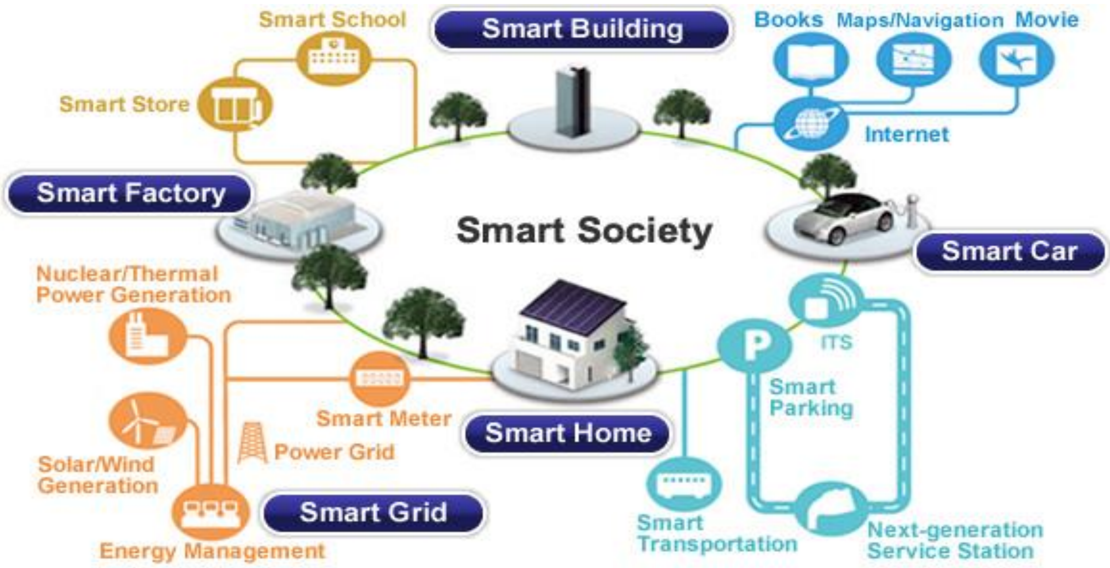

Figure 9: After http://kr.renesas.com/edge_ol/technology/01/index.jsp

The application scope in this context includes the security of critical infrastructures, information exchange, access rights and authorizations, secure mobile computing, ticketing and payment as well as the security and privacy of personal data, and smart home/building related applications. This application scope needs to be considered within the context of the human end-user and the technical focus is on the integration and development of electronic components and systems, delivering always-connected end-to-end information security and providing trust anchors on which security management can be based. This finally will provide growth areas for new digital services without threatening the individual rights to secure information, secure data handling, and privacy. Knowledge of expectations, doubts and valuations of potential users will guide the technology development, to ensure that new digital services will be perceived as secure/reliable, acceptable and manageable by users, taking the risk into account of a widening gap between those who can and those who cannot deal with digital technology in society.

2.2 Strategy

The overall strategy is to leverage European industry strengths, in the first phase of ECSEL. Focus should be on security and safety of connected components (over the Internet or other networks), but also on trustable components and associated software.

The goal is to select the most promising market opportunities (in Europe and outside Europe, such as the equipment of new cities, by the deployment of Internet of Things, big data exploitation, etc.) to improve/integrate the technical building blocks most appropriate to address these markets.

Understanding of what creates trust, what is experienced as challenges and what kinds of smart society needs exist among users and what kinds of implications to security these include, need to be explored from initial steps of the development and continuously in parallel with it.

On selected application areas, Living labs experimentations shall be based on multidisciplinary approaches, and involve service providers, end users and operators. The Public Authorities will generally play significant roles in these experiments, both through Public Procurement and as evaluator / regulator. The experiments shall provide actual feedback, provide ideas for new solutions and services, demonstrate how technology innovations can be adopted, and how “smart” usages can be supported. In addition, these experiments shall contribute to increase end-users trust, which is mandatory for a sustainable growth of the corresponding market. On another end the lack of public implication and slowness in decision process favours the emergence of solutions driven by the market and/or usage brought by end-users (e.g.: social networks, services for taxi services, tourist lodging, etc.). In this perspective, Public/Private partnership has to be considered also as a strong vector of development.

In both cases development and implementation of the Smart Society solutions will need from one side public acceptance and from the other side deep understanding of the societal needs and consequences of the Smart Society. All these aspects are strongly connected with culture of the European societies, being different in different regions. Thus, the Smart Society addressed solutions and innovations will much better harmonize the European way of life, values and societal preferences when developed in Europe.

The priority is to support projects aiming at higher TRL solutions. This will include the definition and development of application specific architectures, higher level building blocks and subsystems based on adopted or modified existing components and recognized opportunities for new services.

Low TRL topics include investigations on new algorithms and protocols, data processing and sharing schemes, protection of secure architectures (embedding cryptography and Secure Information Sharing solutions) against new attacks on data safety and security (e.g. tapping, manipulating, spying or copying), authentication and adaptability of security mechanisms. New concepts and solutions should aim at user acceptance by ease of use and protection of personal data privacy. From the end-user viewpoint one of the key elements concerning interaction with the Smart Society is the secure and seamless authentication to services of the Smart Society. A specific goal is to investigate and evaluate different authentication techniques and their combinations from various aspects (e.g. usability, non-intrusiveness, privacy) in collaboration with users in order to identify requirements for the usable and secure authentication and seamless user experiences in the Smart Society.

Transverse to low and high TRLs, in the context of Smart Society, massive introduction of IoT will, for sure, pose a lot of questions around privacy, data security and policy making. So in order to set up a legal framework to protect citizens, standardization is a key element that is also necessary to boost European competitiveness and will ease IoT deployment and its interoperability in a secured environment.

2.3 Impact

Smart society is a worldwide topic.

The impact pursued by ECSEL includes European independence on critical assets, European leadership for the Internet of Things, European assets development, and competitiveness of European industry on a world-wide market.

2.3.1 European independence for security enabling components and systems

The aim is to ensure availability of trusted components and subsystems as building blocks for smart applications. In particular, all critical hardware and software components with respect to security shall be available from European sources (including sensors, actuators, sensor networks, gateways, servers, middleware, etc. for IoT/M2M support), and be independent as much as possible from US and Asia solutions.

2.3.2 European leadership for Smart and Connected Things (including Internet of Things)

Low-cost components and reference architectures, exploiting short range wireless connectivity with demonstrated benefits in applications such as (but not limited to) home/building automation, home entertainment, payment and ticketing, indoor localization, security and safety and more generally leveraging the “internet of things” in European and ECSEL leading applications.

2.3.3 European assets protection

Focused demonstrations of critical functions, such as end-to-end security, to protect the integrity of the data and guarantee the authenticity of the transmitters. These functions could be deployed in different application areas of ECSEL, and could benefit from space and terrestrial navigation, communication, positioning and observation. The impact includes reduction of attacks on critical infrastructures, avoiding theft of digital identity (e.g., in payment transactions), and opening the way to new European interconnected applications – in addition to increased emergency management capabilities, increased safety and security of road, air, rail and marine transports infrastructures.

2.3.3.1 Public awareness of Europe’s efforts on Safety and Security

Field demonstrations of selected applications, involving such components and subsystems in urban spaces or areas (such as cities, airports or buildings) with digitalization and more connectivity and with impact on safety, security, and privacy.

2.3.3.2 Reducing time to market of European innovations

Innovative architectures combining smart devices with broadband connectivity, enabling new digital life and new digitalization (including interactive e-shopping, video surveillance and conferencing, online gaming, etc.) with guaranteed and adequate privacy.

2.3.3.3 Opening up new market opportunities for European industry

Development of today's leading European companies with secure and safe products (components manufacturers, equipment or systems integrators) as well as new actors, in the very fast growing markets of secure and safe solutions for the smart digital society.

2.4 Cross references

The Smart Society chapter is at the heart of the application chapters of this MASRIA with strong links to the other application chapters. Considering different aspects of human life, the following application business areas can be distinguished, addressed in the different MASRIA chapters.

Aspect of life	Application business area	MASRIA Chapter
We breathe	Smart Health	4 Smart Health
We need energy	Smart Energy and Smart Grid	3 Smart Energy
We live/work in	Smart Home, Smart Building and Smart Cities	**2 Smart Society**
We move around	Smart Mobility, Smart Car and Smart Logistics	1 Smart Transport
We work	Smart Manufacturing and Smart Factories	5 Smart Production

While most aspects are addressed in other chapters, the businesses related to the built environment are unique to this Smart Society chapter: Smart Home, Smart Building and Smart Cities. Moreover, a smart society is more than the built environment (the people that live in it!).

Some of the core technologies required for the smart society building blocks (in terms of devices, associated integration technologies, embedded software and reference architectures) are expected to be developed in the context of the "Cyber-Physical Systems" and "Smart System Integration" technology domains of ECSEL.

Related applications can be found in several areas:

Smart Health
1) Fall detection devices
2) Sport and fitness sensors
3) Distant health monitoring and preventive health care
4) Monitoring of daily patterns of elderly and detection of abnormalities

Smart Home

1) Home entertainment: remote controls, game controllers, smart TV controls, context aware media services, etc.
2) Home automation: robots, time management & mobility services, fire detection, weather station, smart energy management, etc.

Smart Buildings
1) Reducing energy cost of large buildings by integration of infrastructures (HVAC, Lighting, …)
2) Increased safety and security by integrated presence detection through sensor fusion
3) Productivity enhancement through asset tracking based analysis of process flows
4) Comfort enhancement through human centric lighting

Smart Cities
1) Digitizing the information flow about actors and activities in the city, enabling improved city government, urban planning and city branding
2) Introduction of connected omnipresent sensors within the city infrastructure to gather city data
3) Analysis and interpretation of smart city data to improve city government and urban operations, including asset management
4) Exchange of city data between cities to share best practices and to collaboratively accelerate development towards smart liveable cities

Smart Mobility
1) Convergence of mobility as consequence of the urbanization: Using different transportation systems with one media for access and fare collection (public transport, car sharing, bikes, rental cars, etc.)
2) Secure connectivity for the car to ensure safety, convenience and to manage the urban mobility; secure car2car, car2infra and other communication into and out of the car
3) Secured in vehicle networking especially for safety relevant systems
4) Efficient services for easy navigation and transportation such as multimodal and geo-localisation (e-beacon, Find me) information

Smart Manufacturing and Logistics
1) Security in intelligent networks (e.g. machine to machine communication) and industrial automated control systems
2) Communication and access in open systems; protection by end2end security
3) Trusted electronic IDs for both man and machines
4) Protection of the critical infrastructure by de-centralized security architectures

Further applications are foreseen in all kind of autonomous devices using new energy harvesting approaches as well as in versatile devices for multiple applications (supporting cognitive radio).

2.5 Schedules/Roadmaps

Visible results are expected as follows:

Short term: availability of core technology building blocks and reference designs, preliminary demonstrations of pilot systems, and initial technology roadmapping for the next steps based on market priorities (including identification of needs and critical aspects based on user understanding and co-innovation through collaborative projects).

Mid-term: demonstration of innovative system architectures based on these building blocks and reference designs; consolidation of technology roadmapping.

Long term: co-developed concepts for trusted smart society services, strategies for creating trusted solutions, demonstration of user trust and acceptance; evidence of the actual support to implementation of innovative digital services for a smart society. Extensive living lab experimentations, spanning the whole duration of the program, fed by technology innovations, contribute to their integration, and support the demonstrations.

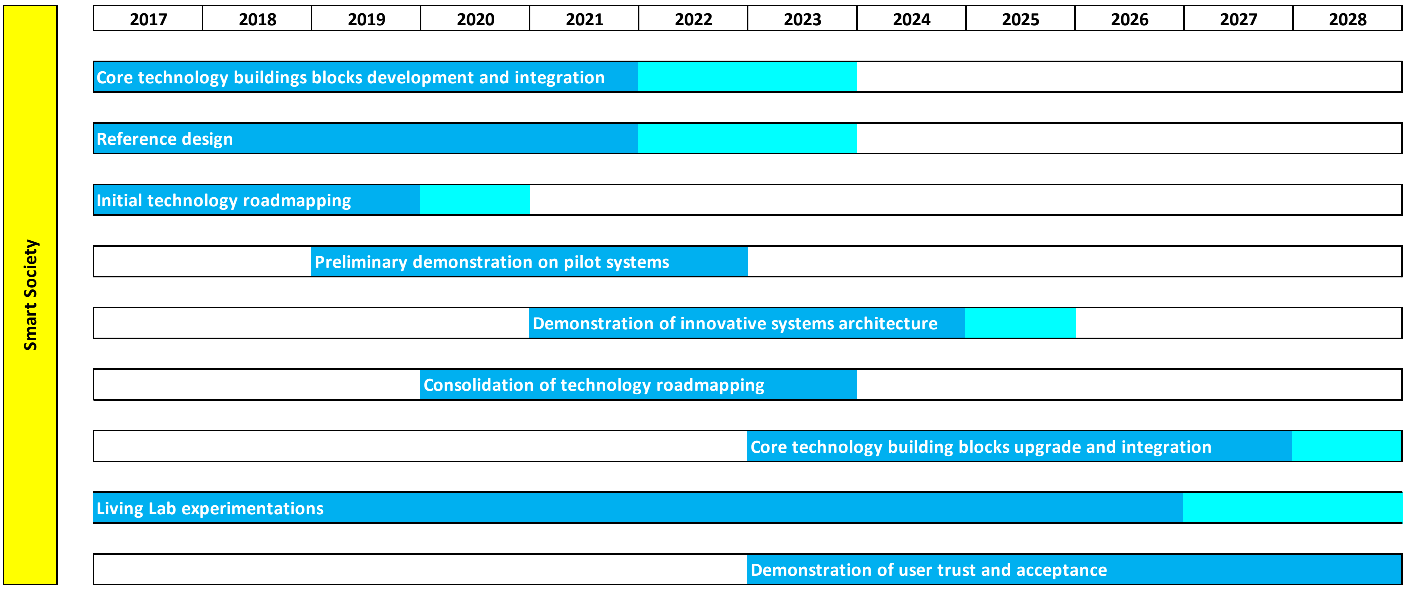

Figure 10: Expected visible results

3 Smart Energy

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

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

3.1 Objectives

Significant reduction of primary energy consumption along with the reduced carbon dioxide emissions [1) 2) 3)] is the key objective of the Smart Energy chapter. Electronic components and systems (ECS) are key enablers for higher efficiencies and intelligent use of energy along the whole energy value chain, from generation to distribution and consumption. Enhancing efficiency in the generation, reducing energy consumption and carbon footprint are the driving forces for the research in nano/micro-electronics, embedded and integrated systems in order to secure in all energy applications the balance between sustainability, cost efficiency and security of supply.

First success in the implementation of measures is visible. According to the IEA[4)] renewables accounted for nearly half of the growth in global electricity generation capacity in 2014 and the rise of distributed generation, smart grid and storage technologies are rapidly changing the way energy is supplied and consumed. The first time in the reporting the emissions of carbon dioxide (CO_2) from the energy sector did not rise although the world economy grew by 3% in 2014.

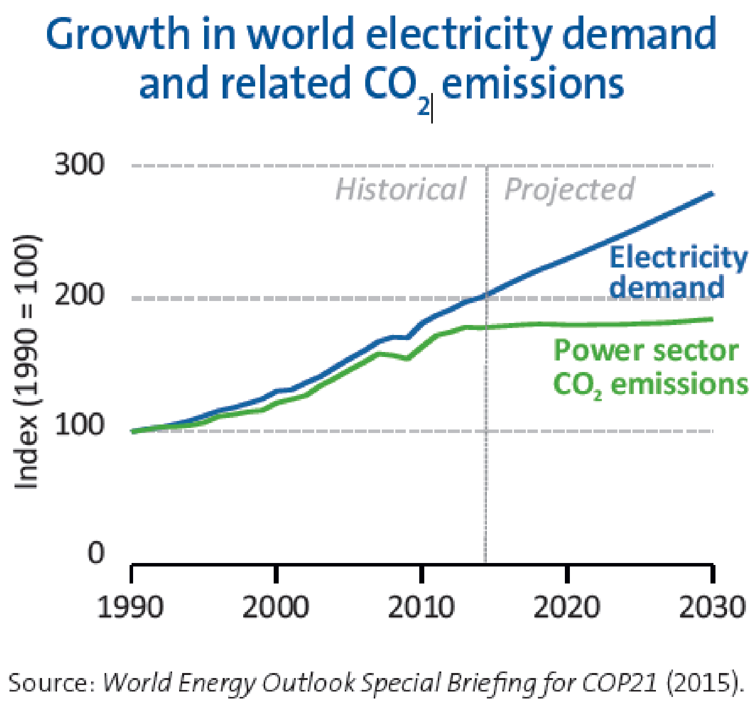

Figure 11: The 1st time in 2014 we observe CO2 emissions stalled despite growing economy[4)]

3.2 Strategy

Three main domains were in the past and will be in the future in the focus of upcoming research for ECS:

1) Sustainable **power generation and energy conversion**
2) Reduction of **energy consumption**
3) Efficient, reliable, safe & secure infrastructure and **energy management**

SMART ENERGY	**NEED**	**ACTION**	**RESULTS**	
	Energy Innovation	*Technical innovation*	*Economic impact*	*Societal Impact*
sustainable **Power Generation** and **Energy Conversion**	Growing energy demand remains, increased share of renewables supported by ECS	Efficiency improvements; lifetime, robustness and reduced life cycle cost including smart maintenance	Competitive position of European industry to create an increase in the EU value chain	Reduced GHG emissions, more efficient renewable energies, creation of local employment
	Efficient distribution	Intelligent and highly efficient converter		
reduction of **Energy Consumption**	New solutions for energy efficiency on system level in general; new innovations for growing applications addressing lowest power demand for IoT solutions, HPC data centres and growing numbers of autonomous systems.	Efficient energy usage; scavenging, intelligent drive controls; smart controls for demand site integration, monitoring on system level by sensor networks, low power architecture, use of low power technologies.	New markets for system solution and services; sensors, control systems, efficient equipment and appliances	Less dependency on energy supply, less costs for energy, new employment opportunities
efficient community **Energy Management**	Efficient and reliable management of demand, distribution, supply and storage including safety and security	Self-organizing grids and multi-modal energy systems incl. energy storage, resilient and self-healing infrastructure, with embedded safety and security, energy scavenging and IoT services	New businesses for management of energy supply and storage, competitive position of European industry	Enhanced involvement and acceptance of citizens for reduced energy consumption Decentralized services with local employment

Figure 12: Strategic areas for Smart Energy components and systems

Research targets have to cover innovations in further enhancement of efficiency, reduction of consumption and by miniaturization of the system sizes. Almost equally important becomes research and innovation on opportunities to reduce greenhouse gas emission by the so called electrification of primary energy intensive processes in industry, infrastructure, buildings, transport and logistics. With the growing use and importance of connected services the energy demand for High Performance Computing (HPC) data centres and for IoT applications, with their highly interconnected devices, is the next dominant factor in the energy landscape. Therefore ultra-low power technologies together with networked demand management are required to cope with this energy challenge. Along with new applications the demand for highly reliable and robust devices has to be supported.

Already today key elements of the infrastructure, the industrial production and public and private services strongly depend on a reliable, safe and secure power supply. The increasing decentralization and interconnection of the systems enhances the need for additional safety and security measures. In addition the capability of self-organization of devices in a smart grid as a system of systems to enable highly efficient use of energy becomes a priority research issue. The potential of digitalization and new topologies has to be leveraged to achieve significant energy savings keeping costs down and comfort high on the user side.
The methodology of vertical integration – from component and system design up to management and services on all grid levels – not only supports to master the future system complexity but also is crucial to achieve the targets according to time to market and cost required for market acceptance.

The necessary innovations in smart energy require applied research including validation and prototyping. Both development and pilot projects can address these areas. Furthermore research activities, developments and demonstration scenarios should be open to different application scales (like home, building, district, city and region but also industry and transport). As an application oriented area the majority of projects and in terms of spent funding should be on research projects with capability to be quickly transferred into market relevant solutions.

3.3 Impact

Smart Energy related research has to support the domestic emissions reduction target of at least 40% by 2030, compared to 1990[5)]. European companies are amongst the leaders in smart energy related markets. With innovative research on European level this position will be strengthened and further employment secured. The research therefore has to address: [6)]

1) **reduction and recovery of losses** by significant values (application and SoA related),
2) **decreased size of the systems** by miniaturization and integration,
3) **increased functionality, reliability** and lifetime (incl. sensors & actuators, ECS HW/SW, ...),
4) **increased market share** by introducing (or adopting) disruptive technologies
5) **the game change to renewable energy** sources and decentralized networks involving energy storage to stabilize the power grid preferably on medium and low voltage levels as well as to manage the intermittence of renewable power generation, offering new opportunities to consumers.
6) **"plug and play integration" of ECS** into **self-organized grids** and multi-modal systems
7) **safety and security** issues in self-organized grids and multi-modal systems
8) **Optimized application and exploitation** of technology advances in all areas where electrical energy consumption is concerned

The ECS for smart energy (incl. components, modules, CPS, service solutions) which support the EU and national energy targets[1) 2) 5)] will have huge impact on the job generation and education if based on the complete supply chain and fully developed in Europe. [6)] The key will be the capability to have the complete systems understanding and competence for small scale solutions up to balanced energy supply for regions. [7)] Mandatory are the capability for plug and play of the components enabled by a broad research contribution from SMEs, service providers including EU champions in the ECS and energy domain.

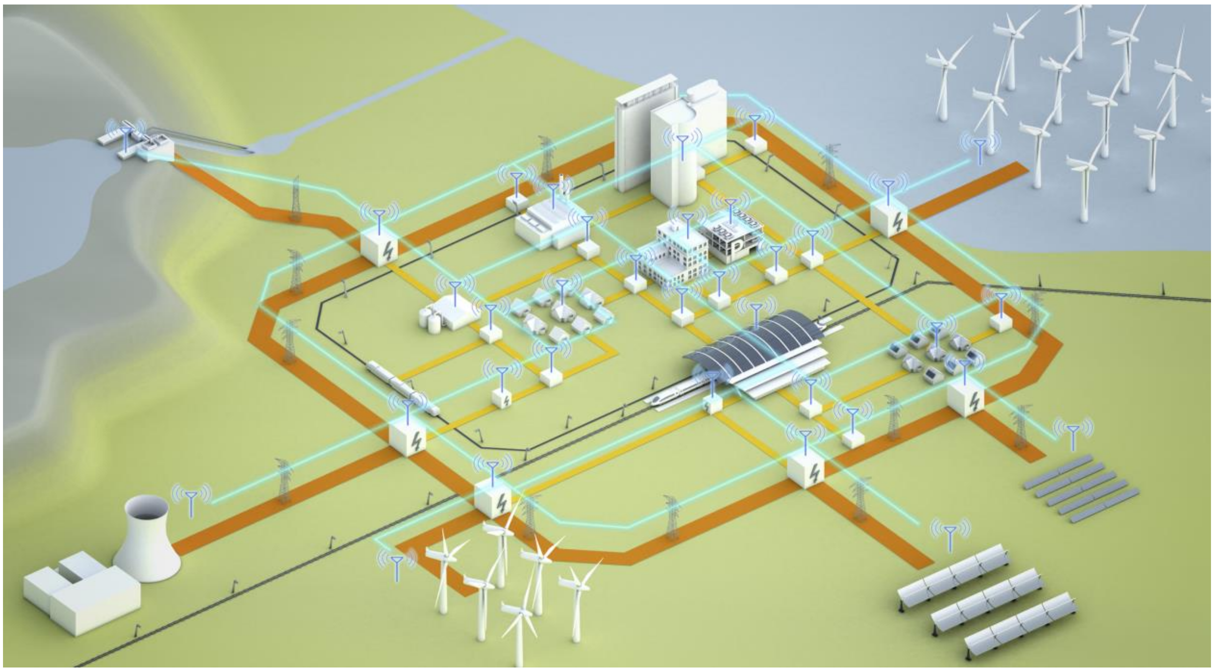

Figure 13: *Smart Energy landscape – from centralized to distributed (PV, wind, biogas, ...) generation and conversion, consisting of High/Medium Voltage grid (orange), Low Voltage grid (yellow) including Communication Network (aquamarine) linking producers and consumers down to regional and community level.*

3.4 Cross references

The ambition of ever and ever higher efficiency and reduced losses in the use of energy requires continuous innovation from semiconductor process to integration technologies (see Part "Essential Capabilities", e.g. semiconductors for power and control, assembly and package technologies). Since safe and stable energy supply is a dominant factor in all application areas, innovation in different kind of domains from **mobility** (e.g. eMobility, Car2X), **production** (e.g. efficient control of sensor networks and actuators for collaborative robots), networked **society** (e.g. safe & wireless communication among networked sensor systems, self-controlled HVAC and lighting) and robust **healthcare** (e.g. high performance storage or converter controls for un-interruptible power supply) can benefit from synergetic solutions (see also *Figure 14*).

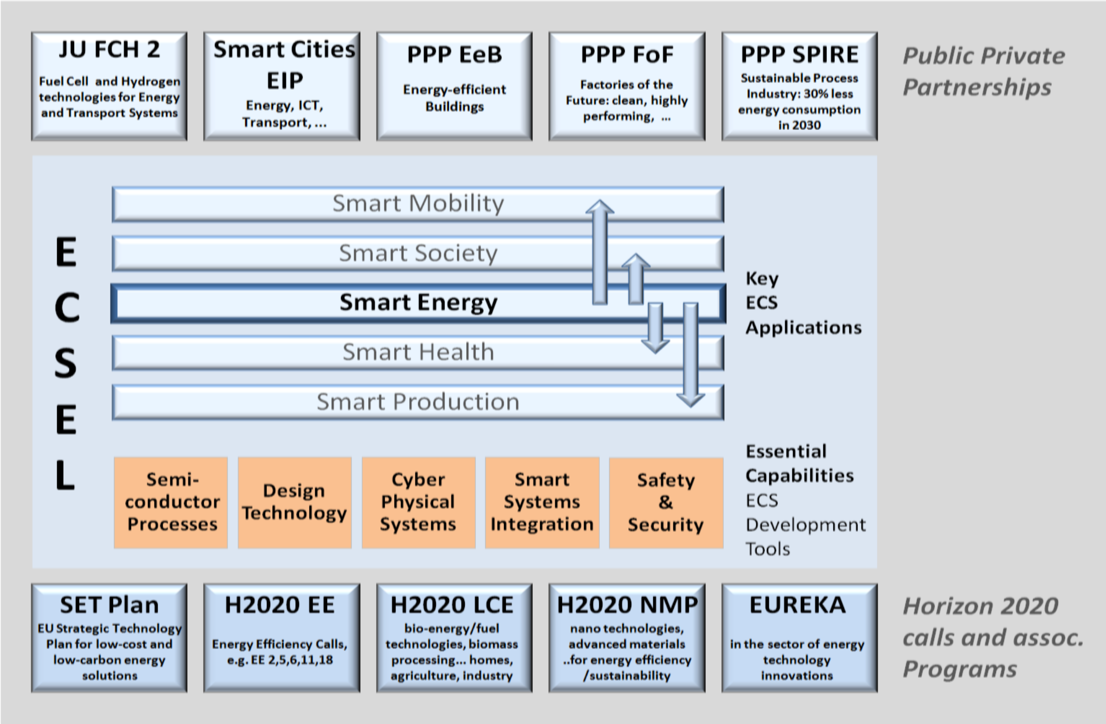

Figure 14: Major cooperation lines for synergy of ECSEL Smart Energy with other chapters and the relations to energy related programs within H2020 and the PPP initiatives

The ECS value chain needs to take advantage of synergies based on generic R&D from basic functionalities in ICT, NMP, Low Carbon and Energy Efficiency technologies up to system relevant design and systems integration including CPS based modelling and real time control, big data and cloud infrastructures with demonstration on use cases in homes, large office buildings, production facilities, agriculture, and infrastructure.

ECSEL will deliver innovative ECS functionality to application-oriented energy research programs as the Joint Undertaking for Fuel Cells and Hydrogen, European Innovation partnership on Smart Cities and Communities, to PPPs for Energy efficient Buildings, Factories of the Future and Sustainable Process Industry to generate competitive answers for Europe’s challenges described in the SET plan (*Figure 13* and Ref. [6) 7)]).

References:

1) *OUTCOMES OF THE U.N. CLIMATE CHANGE CONFERENCE IN PARIS - 21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21) November 30-December 12, 2015* http://www.c2es.org/international/negotiations/cop21-paris/summary.
2) *COM (2014) 15 final – A policy framework for climate and energy in the period from 2020 to 2030, Brussels January 2014 – The so called 20-20-20 targets.*
details see in : http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0015&from=EN
3) *"Leaders´ declaration G7 summit, 7-8 June 2015, p15 and following:*
"... commitment to the elimination of inefficient fossil fuel subsidies ...."; "...common global goal of GhG emissions reduction ...of 40 to 70% by 2050 compared to 2010..." ;
" We will strengthen cooperation in the field of energy efficiency and launch a new cooperative effort on enhancing cyber security of the energy sector. And we will work together and with other interested countries to raise the overall coordination and transparency of clean energy research, development and demonstration, highlighting the importance of renewable energy and other low-carbon technologies. We ask our Energy Ministers to take forward these initiatives and report back to us in 2016."
https://www.g7germany.de/Content/DE/_Anlagen/G8_G20/2015-06-08-g7-abschluss-eng.pdf.
4) *IEA Ministerial Statement on Energy and Climate Change, 18 November 2015, http://www.iea.org/publications/freepublications/publication/Energy_Matters_Brochure.2.pdf.*
5) *European Commission - Press release: Energy Union and Climate Action: Driving Europe's transition to a low-carbon economy, Brussels, 20 July 2016; http://europa.eu/rapid/press-release_IP-16-2545_en.htm.*
6) *The new Integrated SET Plan, fit for new challenges, Sep 15 2015, adopted by the EC as the new* ***Strategic Energy Technology (SET) Plan****. The upgraded SET Plan is the first research and innovation deliverable on which the fifth dimension of the Energy Union will be built. Building on an integrated approach going beyond technology silos,* ***the upgraded SET Plan proposes ten focused research and innovation actions to accelerate the energy system's transformation*** *and create jobs and growth, ensuring the European Union's leadership in the development and deployment of low-carbon energy technologies.*
For more information see: https://ec.europa.eu/energy/en/news/integrated-set-plan-fit-new-challenges.
7) *EU project EXPRESS - Mobilising Expert Resources in the European Smart Systems Integration Ecosystem deliverable D3.2, chapter on Energy and lists of Drivers, Barriers and Application Opportunities for SSI in the Energy sector based on analysis of the 15 international and national roadmaps and strategy documents. These opportunities respond to needs identified by actors outside of the ECSEL community to create business with the sectors who published these strategy documents. Examples include the integration of tracking control electronics and the inverter into one device as highlighted by the EUPV Technology Platform, and monitoring devices for analysing the aging of the equipment for Smart Grids etc.*
For more details see: http://www.express-ca.eu/public.

3.5 Schedules/Roadmaps

ECSEL MASRIA 2017	SMART ENERGY Road Map			
1	**ECS for Sustainable Power Generation and Energy Conversion**	**2017 - 2018**	**2019 - 2020**	**2021 - 2030**
1.1	**Highly efficient and reliable ECS** for all kind of electrical energy generation – de-centralized to large power plants, cross link to processes and materials			
1.2	Smart and micro **converter reference architecture** with integrated control			
1.3	**Highly integrated power electronics**, actuators for safe and reliable DC and AC grids			
1.4	**Converter on a chip** or integrated modules			
2	**ECS for Reduction of Energy Consumption**	**2017 - 2018**	**2019 - 2020**	**2021 - 2030**
2.1	**Implementation** of smart electronics **in smart grid nodes** including system integration with communication interfaces			
2.2	ECS for controlled power/drive trains and illumination			
2.3	**Smart electronic components** for (MV/LV)DC power supply implemented in e.g. buildings, factories, infrastructure and vehicles/planes)			
2.4	**Distributed DC network**			
2.5	Smart electronic components for MV/DC grid integration of **storage** and renewable			
2.6	**Fully connected ECS** for e.g. illumination and city energy use			
3	**ECS for Efficient Community Energy Management**	**2017 - 2018**	**2019 - 2020**	**2021 - 2030**
3.1	**monitoring** of energy infrastructure and cross domain services (e.g. maintenance, planning and IoT services)			
3.2	Decreased integration costs in **self-organizing grids**			
3.3	Smart systems enabling optimized heat / cold and el. power supply			
3.4	ECS support for standalone grids and self-organization incl. Scavenging			
3.5	Smart systems enabling optimized **power to fuel** and **coupling of transport and el. Power sector**			
3.6	New energy market design. e.g. self-coordinated energy supply in local grids			

RIA – low TRL IA – high TRL

Figure 15: Smart Energy Road Map - for the three strategic domains

Smart Energy	**Short term**	**Medium term**	**Long term**
overall targets embedded in EU strategy	EU targets for 2020 supported (20/20/20) **greenhouse gas** levels reduced by 20% Increase share of **renewable** to 20%. Reduce energy **consumption** by 20% Projection regarding the targets in 2020	ECS for recovery of the not matched targets in 2020 and preparation for 2030 targets Supply by European manufacturing of ECS secured	EU targets for 2030 supported by ECS from European suppliers: share of renewable energy in the electricity sector would increase from 21% today to at least 45% in 2030
targets for energy supply from communities to regions	**1st order decentralized** simple connected local systems – higher efficiency and first integration approaches including power system services (last mile – up to 100 users)	**2nd order decentralized** regional area balanced energy supply (villages and cities up to 100.000 users) ECS capable for efficient fast reaction oversupply and peak load management	**3rd order decentralized** on country level balanced energy supply

Figure 16: Smart Energy Road Map - for short to long term targets in relation to overall EU strategy

#	Topic \ Time	2015	2016	2017 - 2018	2019 - 2020	2021 - 2030
1. ECS enabled sustainable power generation and energy conversion						
SET,EIP, NMP, FoF, Smart Cities, ... milestones	*M1.1: tbd*					
	M1.2: tbd					
	M1.3: tbd					
Smart Energy milestones	*M1.4: Market launch for 2nd generation EV and the first small scale deployment a FCEV*					
	M1.5: Mass production of EV + medium scale production of FCEV + ICE vehicles transformed to hybrid concepts					
	M1.6: Mass production of a 3rd generation commodity priced EVs					
1.1	Energy management					
1.2	Energy efficiency and CO2 emissions control					
1.3	Energy harvesting					
1.4	Inductive and bidirectional charging					
1.5	Energy storage management (for batteries and fuel cells)					
1.6	Power electronics (form factors, efficiency, automotive quality) for drive train and auxiliaries					
1.7	Solutions for safety and reliability and security					
1.8	Connected powertrain					
2. ECS enabled reduction of energy consumption						
SET,EIP, NMP, FoF, Smart Cities, ... Milestones	*M1.1: tbd*					
	M1.2: tbd					
	M1.3: tbd					
Smart Energy milestones	*M2.4: Conditional automated driving in low speed and less complex driving environments, e.g. in parking lot and in traffic jam situations on one-way motorways.*					
	M2.5: Conditional automated driving at higher speeds in environments with limited complexity, e.g. highways.					
	M2.6: Highly automated driving in most complex traffic situations					
2.1	Sensing, actuation and data fusion – in- vehicle and with sensors and actuators in the environment					
2.2	Environment recognition					
2.3	Traffic scene interpretation					
2.4	Mapping and routing					
2.5	Control strategies & real time data processing					
2.6	Verification, validation & simulation for automation					
2.7	Fail safe and secure operation					
2.8	Cooperative systems					
2.9	Human-vehicle interaction					
2.10	Infrastructure supporting autonomous transport					
2.11	Positioning and navigation					
2.12	Cognitive modelling					
2.13	Interacting safety					
2.14	Lifetime, reliability, robustness and functional safety					
2.15	Certification and testing					
2.16	Intelligent in-vehicle networking and CAR2X communication					
2.17	Quality of services in extreme situations					
3. ECS enabled efficient community energy management						
SET,EIP, NMP, FoF, Smart Cities, ... milestones	*M1.1: tbd*					
	M1.2: tbd					
	M1.3: tbd					
Smart Energy milestones	*M1.4: Market launch for 2nd generation EV and the first small scale deployment a FCEV*					
	M1.5: Mass production of EV + medium scale production of FCEV + ICE vehicles transformed to hybrid concepts					
	M1.6: Mass production of a 3rd generation commodity priced EVs					
3.9	Online status/location monitoring and trajectory re-routing					
3.10	Intermodal cross country travel information					
3.11	Access and parking management					
3.12	Fleet management					
3.13	Predictive online traffic information (using social media and historic information from big data)					
3.14	Standardization of intermodal communication					
3.15	Rail energy use and storage management					
3.16	Aerospace SW platform for 100% operational availability and reliability, full situational awareness, human centered operation, seamless connectivity with the in-flight and ground environment					
3.17	Cost efficient, flexible reconfigurable, dependable and safely operating satellite systems for Smart Environment developments					
3.18	Assistive transport networks systems (e.g. for the elderly living)					

Figure 17: Roadmap for Smart Energy with milestones indication

Legend:

- planned in WP of ECSEL
- market oriented Milestone from domain
- derived milestone, when results from IAs needed
- derived milestone, when results from RIAs needed

4 Smart Health

4.1 Objectives

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

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

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

Based on the general trends mentioned above four main objectives are defined:

Objective 1: Transform from now to 2025 healthcare from state of the art to standardized care in order that existing medical devices and medical supplies become more and more applicable outside the hospitals. The transformation should result in gradual migration to a more controlled uniform and efficient delivery of care for the population, the decrease of cost and quality differential between care providers, patient management not only local at the medical doctors and in hospital but largely spread.

Objective 2: Creation of an open Digital Health Platform ecosystem, enabling cost effective development and validation of healthcare appliances and applications. The platform will provide an open environment, enabling a wide range of collaboration opportunities and easy market access for new applications. The platform is open for new appliances and applications by providing API's (Application Programming Interfaces), while taking safety, security and privacy into account.

Objective 3: Mobile healthcare systems based on micro-/nano-electronics, to increase sustainability and efficiency of health systems and support the improvement of quality of life for patients, in particular of elderly people with chronic disease. In the end, dedicated sensor systems have the potential to significantly reduce number of casualty and unscheduled hospitalizations. Patients should be more self-empowered to manage their disease by their own.

Technology can enable a new form of patient care that effectively moves away from a hospital setting for patients that require routine monitoring with their well-being and comfort is enhanced when in a home environment. This also frees up hospital beds and has the potential to reduce the pressure on hospitals.

Objective 4: Medical equipment and devices are evolving fast, especially in the changeover from open surgery to closed (minimal invasive) surgery.

Innovation in imaging (e.g: functional imaging, higher resolutions), multi-model imaging (e.g. HIFU) and image guided intervention will open up complete new treatments, workflows and markets.

4.2 Strategy

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

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

All three challenges imply a major focus on improved productivity.
These grand challenges are shown in *Figure 18*, which visualizes the health continuum.

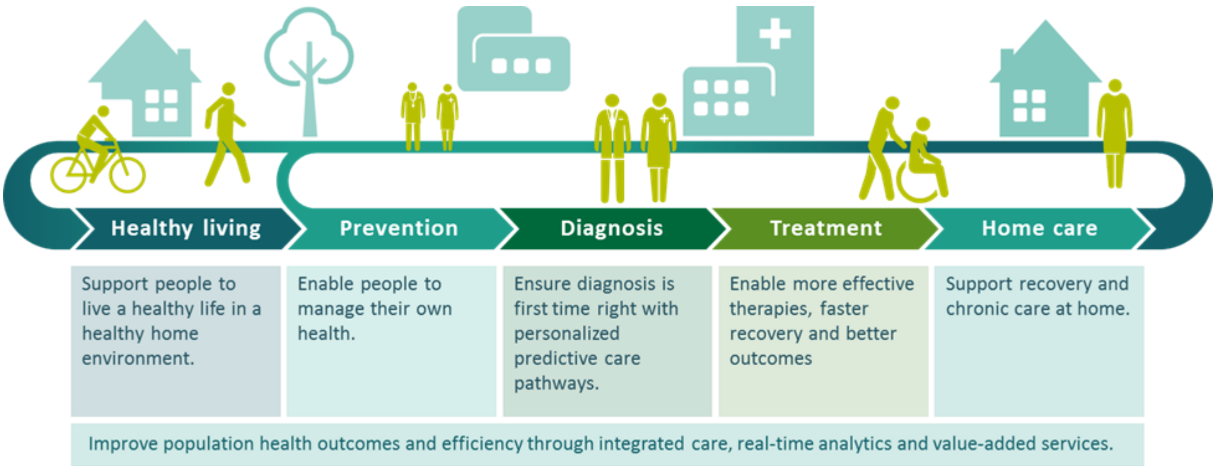

Figure 18: Health continuum encompassing Home, Hospital, and Heuristic Healthcare

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

Figure 19: Key requirements for the Grand Challenges

Figure 19 describes the overall characteristics and priorities for the different healthcare challenges. All forms of healthcare should be as cost–effective and accurate as possible. However, trade-offs are different in each case. For example, Home Healthcare is characterised by low cost and ease-of-use rather than high accuracy, while for Heuristic Healthcare accuracy is paramount even if it comes at a higher cost and/or requires more highly trained personnel.

4.3 Impact

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

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

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

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

Benefits for the European society at large are amongst others creation of a European ecosystem around digital healthcare; contributing to the reduction of growth of healthcare cost; raise people's healthy life years; improving quality of life and productivity of work force; and decreasing or considerably slow down increase of number of morbidity among society.

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

To realise these benefits, significant advances in nano-electronics, medical sensing, home monitoring, data processing and medical ICT are required. The ambition is to influence all stakeholders in the entire health continuum.

4.4 Technical challenges

The next section describes each of the Grand challenges with their ambition, R&D&I priorities and expected results.

4.4.1 Grand Challenge 1: Home Healthcare

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

Achieving highest quality of life for elderly, impaired and people with chronic diseases at the lowest cost to society, is only possible if they can fully function in society, independent of peer or medical support and without being institutionalized, but nevertheless be provided with adequate protection, security and care ('Independent Living'). Patients with chronic illness should participate in their own care for health rather than being subject to healthcare services. Electronics-based solutions will assist people who have limited mobility or impaired vision or hearing, and those with cognitive impairment – for example, people with dementia or mental health issues. Next to health and wellness for people living at home, home care and home treatment will be essential parts of

modern, integrated, patient-centric healthcare systems. Information on environmental factors as air quality and allergens builds a decision basis for a healthier lifestyle. Instead of patients travelling to their general practitioner's office or an out-patient clinic for check-ups, their 'vital signs' measurements (blood pressure, heart rate, etc.) and corresponding data will be securely communicated to the relevant healthcare services on a daily basis to guarantee that they receive the necessary attention. For patient self-management and economic reasons, national governments already strongly support the relocation of care from the hospital to the home, the community or the general practitioner's office.
Home healthcare can be extended to healthy people to encourage preventive behaviours, such as lifestyle changes, via personalised healthcare portals and electronic coaching tools. Knowing about the environmental influences enables healthy people to act accordingly, to stay healthy and avoid chronical diseases and hospitalization as much as possible. Based on genetic and biomarker-based predictive profiling, healthy people will be supported in making healthy behaviour choices, customised to reduce their personal health risks.

High priority R&D&I areas:

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

Expected achievements:

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

4) Advanced tele-rehabilitation services (e.g. with portable robotics)
   a) Adherence to long-term therapies
   b) Personalized therapy through smart implantable devices
   c) Peripheral medical devices to power and control ultra-small diagnostic or therapeutic implanted devices
5) Technological cross-application advances
   a) Secure/private tele-monitoring networks
   b) Wearable and in vivo electronics and smart integration to measure biometric parameters and related treatments
   c) Personalization and consumerization
   d) Localization techniques (indoor and outdoor)

4.4.2 Grand Challenge 2: Hospital Healthcare

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

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

High priority R&D&I areas:
1) Advanced imaging based diagnosis and treatment
2) Screening for diseases
3) Intervention / therapy
4) Smart environments, devices and materials
5) Remote diagnosis and monitoring / support

Expected achievements:
1) Advanced imaging based diagnosis and treatment
   a) Robotic image-guided surgery
   b) Improved image detectors that capture greater detail
   c) Advanced imaging for several modalities
   d) Smart micro-tools for advanced medical treatment (surgery, biopsy, …)
   e) Image-guided biopsy and treatment procedures
   f) Multi-modal heterogeneous data processing for advanced decision support
2) Screening for diseases
   a) Non-invasive screening for disease
   b) Early screening for diseases and improved screening imaging systems
3) Intervention / therapy
   a) Digital patient for planning surgical procedures
   b) Image-guided biopsy, treatment and therapy procedures
   c) Robotic image-guided surgery and therapy for many diseases
   d) Multi-modal, low X-ray dose, accurate visualization and guidance
   e) Smart intervention devices with e.g. image guidance, pressure sensing

    f) Operating room of the future: swallowed or implantable miniaturized capsules with imaging or sensors for diagnosis / surgery / therapy
    g) Patient safety, pharma compatibility and treatment consistency verification
4) Smart environments, devices and materials
    a) Healing environments for improved patient wellbeing
    b) Energy autonomous smart systems with multi-parameter sensors
    c) Smart automated drug delivery with or without smart implants
    d) Adaptive prosthetics, artificial organs
5) Remote diagnosis and monitoring / support
    a) Remote medical intervention and virtual team support

4.4.3 Grand Challenge 3: Heuristic Healthcare

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

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

1) Multi-parameter biosensors for preventive health monitoring and early diagnosis. These will enable 'doctor in the pocket' applications for the rapid measurement of multiple parameters and/or biomarkers. The patient regains control of his/her medical data and the transition from 'simply measuring' to active personal health management is enabled (empowered patient participation). An intermediate step may be the availability of such (still expensive) instruments in the doctor's office.
2) Elimination of the educated guess (trial-and-error) methods currently used to screen chemical compounds for their therapeutic value. Based on heuristic algorithms, large numbers of compounds will be tested in parallel. Availability of (still expensive) instruments in the doctor's office will enable an intermediate learning step with expert (doctor's) support.
3) In determining drug regimens, heuristic healthcare characterises real-time response measurements to drug delivery in order to create individualised prescriptions with minimal adverse effects.

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

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

High priority R&D&I areas:

1) Screening for diseases
2) Intelligent data management
3) Personalized medicine

4) Smart environments, devices and materials

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

A reference architecture and platform combining the enormous amount of connected equipment types and versions is needed to assure interoperability on technical level and information level. This architecture and platform should ensure dependable interoperability in the cloud and over the internet taking into account the large amount of dependability variation in the devices themselves. New sensors and systems are needed to measure and monitor specific health parameters to improve the diagnostic quality and specificity. An infrastructure is needed to manage all the data both in hospital and outside the hospital ensuring data capture, information presentation, security (prevent unwanted access to data), privacy (keep personal information personal and use data for personal needs) and ethics (prevent misuse of data). New decision support techniques using many data sources, including data mining, taking differences in data source dependability into account. New applications will be developed, analysing available data taking security, privacy and ethics into account.

4.5 Cross references

Synergies between ‘Smart Health’ and the other chapters:

Synergy with application chapters:

1) Smart Mobility: Health and wellness technologies can be deployed in automotive settings to improve safety (e.g. sensor networks that monitor a driver’s vital signs and act accordingly). In addition, medical imaging systems could benefit from new electronic power sources developed for electric and hybrid vehicles.
2) Smart Society: the next-generation digital lifestyle should guarantee prevention and privacy of medical data, requiring trusted components. Smart healthcare needs to become part of the smart environment, only this allows ubiquitous support for patients, and providing prevention
3) Smart Energy: Low-power techniques are essential to healthcare monitoring systems using portable or on-body devices. New materials, devices and equipment for solar energy conversion can support the development of new radiation conversion detectors and efficient power converters for imaging systems.
4) Smart Manufacturing: certification of medical equipment implies careful manufacturing using affordable and flexible production tools such as 3D printing.

Synergy with technology chapters:

1) Process technologies: Optimal solutions spearheading More-than-Moore technologies (e.g. microfluidics and gas sensors) will need to be fabricated into low-cost cartridges and platforms to monitor the human body and the environment.
2) Design technologies: Efficient integration of heterogeneous technologies, the achievement of ultra-low power consumption, and high levels of reliability will be required in the complex heterogeneous systems needed in healthcare
3) Cyber-Physical Systems: As most medical equipment will be wirelessly ‘connected’ and will measure multiple physical parameters, secure, adaptive CPS platform architectures are required.
   Standardization and semantic interoperability issues will also be addressed, as well as health-care data mining expert systems.
4) Smart Systems Integration: For multidisciplinary system integration - e.g. for devices ranging from lab-on-chip and point-of-care diagnostics to complex diagnostic, interventional/therapeutic systems. Unobtrusive, mobile health-status monitoring and smart-treatment systems also require multidisciplinary integration and packaging.
5) Safety and Security: Large amounts of patient and non-patient data has to be collected, transmitted and stored securely. Privacy needs to be guaranteed at all times. Drug delivery and surgical interventions become automated, intrinsic safety has to be guaranteed.

4.6 Schedules/Roadmaps

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

1 - Home Healthcare	1.1 - Disease prevention, promotion of healthier life-style, remote coaching and information on environmental factors	1.1.a	Life-style profiling and activity recognition
		1.1.b	Personal lifestyle monitoring and guidance (diet, activity)
		1.1.c	Smart assistive services to support daily life activities
		1.1.d	Oral health measurement for regular assessment of home oral hygiene efforts
		1.1.e	Smart textiles with connected sensors and energy autonomous systems
		1.1.f	Improvement of wellbeing through environmental influences e.g. lighting
		1.1.g	Wellness environments for enhanced mental health and wellbeing
		1.1.h	Environmental sensing for air quality monitoring, detection of allergens, ...
	1.2 Remote health monitoring and support (e.g. for the elderly)	1.2.a	Personal health management
		1.2.b	Autonomy monitoring and pre-dependency assessment
		1.2.c	Flexible textile-based systems for on-body diagnostic and therapeutic functions
		1.2.d	Domestic accident detection, monitoring, warning and emergency alert
		1.2.e	Advanced tele-health, including personalized facilities to engage patients in the self-care process, and early identification of potential personal risk factors
		1.2.f	Home monitoring systems for health related parameters by non or minimally invasive molecular diagnostics
		1.2.g	Treatment support and control (support for quantity and time of drug taking)
	1.3 - Remote disease management	1.3.a	Prevention of hospitalization for chronic diseases for a large elderly population
		1.3.b	Tele-medicine, home diagnostics monitoring, point-of-care screening devices, ultra-small smart implanted and on-body diagnostic and therapeutic devices, broadening diagnostic scope
		1.3.c	Non-invasive measurement e.g. blood parameters, bio markers and (de)hydration
		1.3.d	Smart devices, e.g. e-inhalers, bandages, in vivo treatments and new responsive biomaterials
	1.4 - Advanced tele-rehabilitation services (e.g. with portable robotics)	1.4.a	Adherence to long-term therapies
		1.4.b	Personalized therapy through smart implantable devices
		1.4.c	Peripheral medical devices to power and control ultra-small diagnostic or therapeutic implanted devices
	1.5 - Technological cross-application advances	1.5.a	Secure/private tele-monitoring networks
		1.5.b	Wearable and in vivo electronics and smart integration to measure biometric parameters and related treatments
		1.5.c	Personalization and consumerization
		1.5.d	Localization techniques (indoor and outdoor)

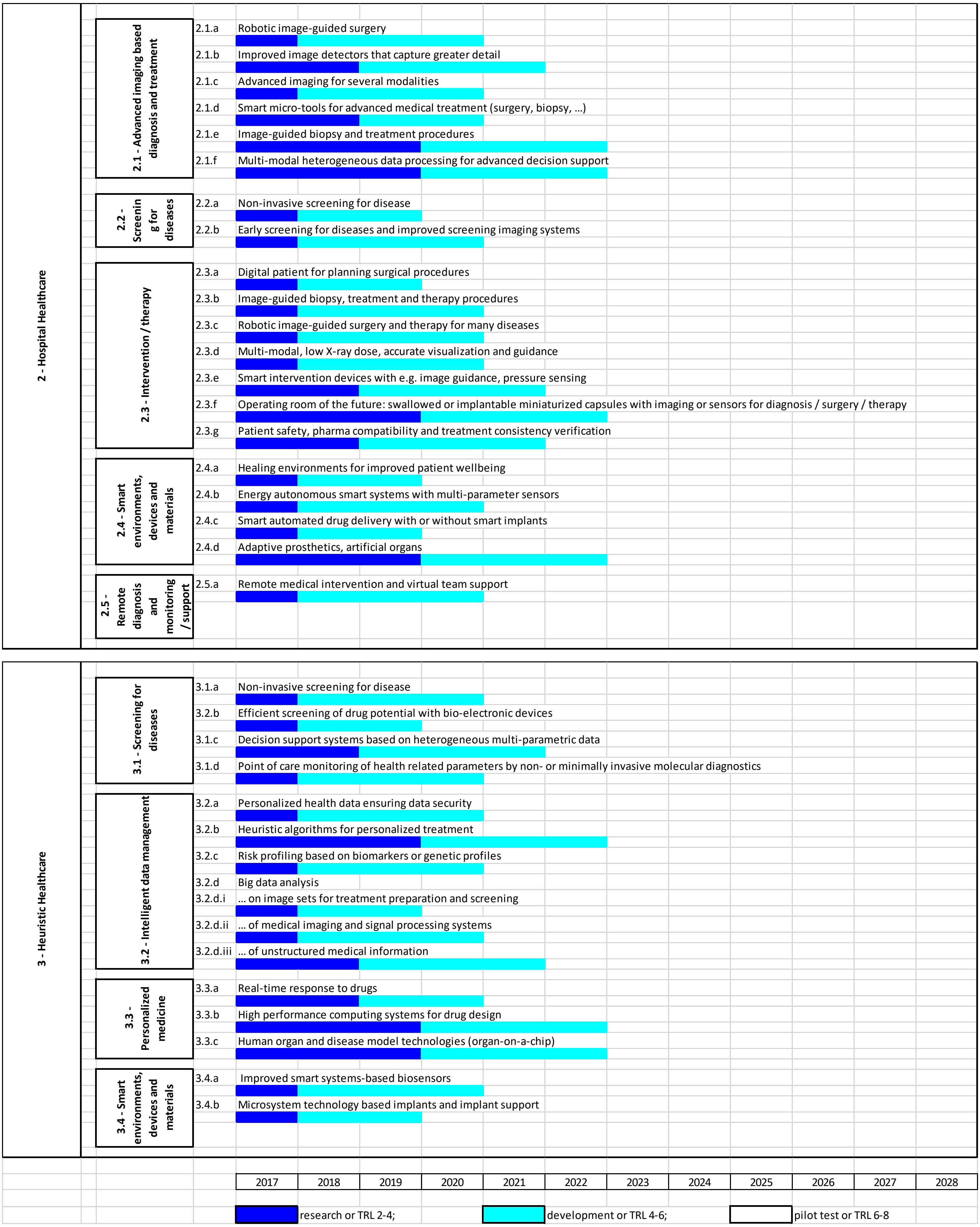

Figure 20: Roadmaps for Smart Health

5 Smart Production

The strengthening of European leadership in automated production of complex and technologically demanding products by all means of advanced electronic components and systems (ECS) and information and communication technologies (ICT) is crucial to master the digital transformation of the European industry and is precondition for the reindustrialisation of Europe.

Smart sustainable and digital automated production in Europe can only be achieved if the top level needs identified by company strategies will be fulfilled sufficiently:

- Digital and highly automated production
- Flexible sustainable production with customization capabilities
- Safe and secure production
- Collaborative production in efficient supply chain networks
- Coverage of the entire product life-cycle
- Improved Overall Equipment Efficiency (OEE)
- Overcoming stakeholders hesitations

Digitising the production and multi-stakeholder collaborative automation of the production phase along the entire value chains and covering an efficient product life-cycle management have been identified as key to European competitiveness in production and thus economic and employment growth.

5.1 Objectives

The key objective of sustainable ‘Smart Production’ is multi-stakeholder collaborative automation and digitisation of the European industrial production by means of advanced electronic components and systems (ECS) covering the entire product lifecycle from product design, manufacturing, product in-use till recycling. The enabling of such automation and digitisation requests platforms that significantly simplifies engineering, operation and maintenance. Thus the migration from legacy to next generation of production can be supported. This would even enable automation and digitisation in production sectors in which automation is yet hardly present.

The European industrial production faces strong global competition. The further development of the European leadership in automation and process control is key to increase European competitiveness in production. Thus, world leading automation and disruptive production technologies enabled by innovative ECS form a cornerstone for the reindustrialisation of Europe. Examples of innovative ECS are: cyber-physical production systems, human-machine interaction, autonomous manufacturing equipment, advanced sensor systems, high-integration manufacturing technologies, integrated additive and subtractive manufacturing processes, high-speed closed-loop control and traceability technologies, secure real-time (wireless) communication and embedded smart software.

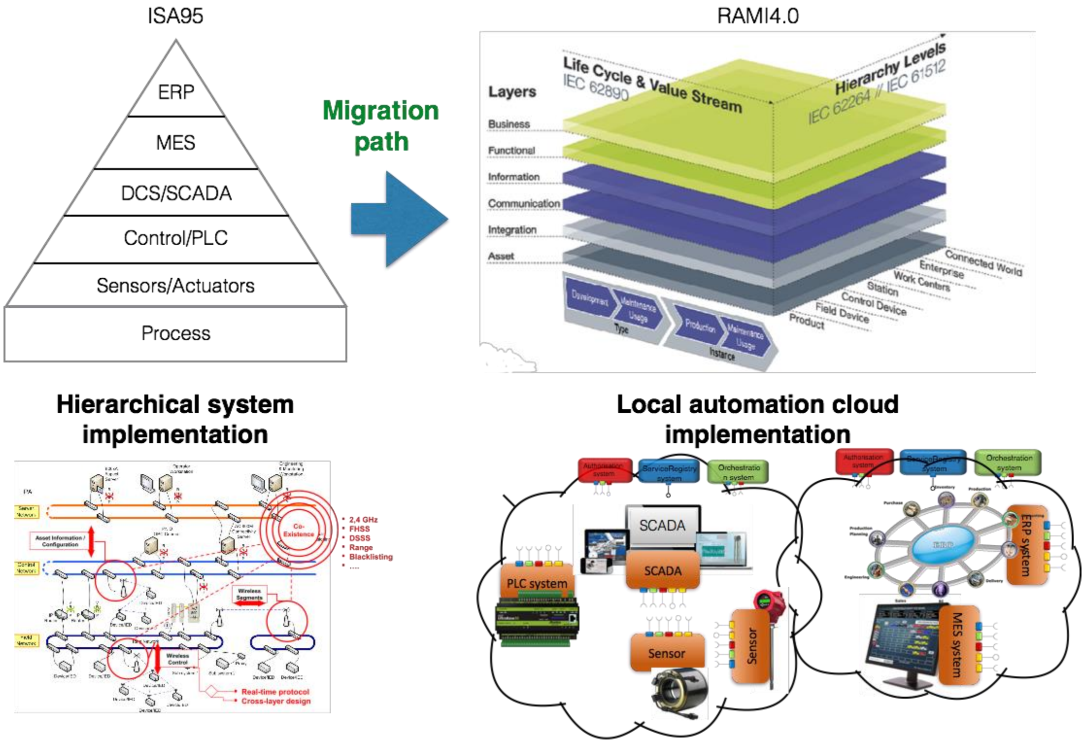

Figure 21: Migration from strict hierarchical systems to more flexible, scalable and collaborative structures

Leading European producers are demanding improvements regarding availability, flexibility and controllability in integrated, secure and functional safe production systems, for supporting their ambitions on overall equipment efficiency (OEE), energy efficiency, raw material yield, flexible and sustainable manufacturing. They are facing the demand for lot-size one production (personalization) and thus, need to ensure availability, flexibility and controllability in integrated, secure and safe production systems. Further there is a trend of increasing hybrid cross-over products/embedded IT and integrated services. Similarly, SMEs are facing numerous problems in ensuring access to small batch manufacturing capabilities. Transformation opportunities are numerous when companies cross traditional boundaries. Hybrid solutions that help such crossovers are mandatory, and this calls for next generation solutions.

In the ECSEL focus of ‘Smart Production’ are both the European manufacturer improving their production efficiency along the entire value chain networks as well as the industrial equipment supplier and tool vendors providing innovative automation solutions, process control and logistics management systems.

Therefore ECSEL will complement the efforts by H2020, EFFRA and Spire PPPs in the field of manufacturing and process automation by addressing new and demanding capabilities to be provided by next generation of leading-edge digital platforms capable of exploiting the capabilities of cyber physical systems (CPS), industrial internet of things (IIoT) and system of systems (SoS) technologies.

5.2 Strategy

Sustainable integrated 'Smart Production' research and innovation (R&I) in ECSEL will focus on a true holistic system approach which includes platforms with suitable system engineering and management tools as well as methodologies enabling the exploitation of new CPS, IIoT and SoS capabilities. Thus providing digitization and automation functionalities in the domains of:

- Procedures, methods and tools for planning, managing operating and maintaining collaborative automation environments, as well as support for the transformation from legacy to future system
- System integration of smart CPS service capabilities such as sensing, communication, analytics, knowledge management, decision support, control, actuation, resulting in smart maintenance and smart production operation
- Improved production system integration along the three production axes, product life cycle, value chain and enterprise, enabling and improving consistent quality and delivery reliability, availability, flexibility, improved controllability, improved interoperability, and production planning, security and increased utilisation of production capacities along the value chain
- Autonomous optimization of life cycles, value chain integration and enterprise efficiency and flexibility
- Enabling of collaborative automation environments comprising both human and technology while maintaining security and functional safety under real-time conditions and w.r.t. their interdependency
- Enabling scalable large systems featuring distributed big data to useful information transformation in collaborative environments.
- Tools, methodologies and technologies enabling:
  - The engineering of collaborative automation environments,
  - The migration from current legacy systems and
  - The future systems evolvement
- New digital manufacturing methods, equipment and tools powered by sensing, tracing, data acquisition, data processing and analytics and cloud connectivity
- Large Innovation Actions and focused RIA projects supporting digitalization of production, product life cycle optimisation, value chain network integration – application independent and across domains

The TRL level for the electronics systems and their embedded software to be addressed is TRL2-4 for research and innovation projects and TRL4-8 for innovation projects.

This strategy addresses and supports the identified top level needs for smarter production:

- Digital and highly automated production
- Flexible sustainable production with customization capabilities
- Safe and secure production
- Collaborative production in efficient supply chain networks
- Coverage of the entire product life-cycle
- Improved Overall Equipment Efficiency (OEE)
- Overcoming stakeholders hesitations

5.3 Impact

Comprehensive ECS-and ICT-based solutions for Smart Production will maintain the European industry on the way towards a complete digitalisation of production and therefore fit for the global market.

Large integrated R&D&I projects will enable strong standardisation and early adoption of new and efficient automation and production technologies in Europe. The cooperation along value and life cycle chains in large R&D&I efforts will support collaborative automation technology supporting strong integration within the complex network of stakeholders necessary for efficient and sustainable production. New disruptive production methods, technologies and services are enabled by novel electronics systems and their embedded software; these are exemplarily additive and subtractive manufacturing technologies for various materials like metal and plastics that are seamless integrated in the production chain and that are empowered by new design tools and the digital world. Production line availability, flexibility and controllability/traceability will be improved through increased automation and disruptive production technologies. Thus supporting European production to increase well above average and become globally more competitive.

Large R&D&I projects could foster the building of new cross domain ecosystems especially with high SME-involvement. This will enable the production in Europe of next generation of all types of products, including consumer and professional and of course to face challenging time-to-market, quality and cost targets in a global competition.

5.4 Cross references

The strategy relies on incorporation of new technologies. Particularly important will be advancement in system design technologies, architectures and tools (design, engineering, test verification, deployment and operation), integrating new CPS and smart system technologies like easy to integrate sensor systems, secure wireless high-speed communication ability, labeling technologies like RFID and NFC, standardized interface technologies and production data analytics. Critical success factors will be robustness to industrial production environments, interoperability, validation and standardization, and last but not least security. Also, strategies, technology and methods used and under development for highly automated semiconductor manufacturing addressed in Essential Technologies Chapter 7.1: Semiconductor Manufacturing, Technology, Equipment and Materials, are directly connected with the challenges and opportunities addressed in this chapter.

5.5 Schedules/Roadmaps

Short-term innovations expected relate to design technologies enabling the introduction and migration of smart CPS into production automation and new production technologies.

Mid-term innovations are industrially proven production automation systems with integrated smart CPS. This includes maintenance thanks to real time large data collection.

Long-term innovations are collaborative automation systems enabling radically increased OEE, production being an agile part of society regarding energy efficiency, sustainability and flexible production.

Two major roadmaps related to smart production have recently been developed by EFFRA and ProcessIT.EU [25] [26]; the later focusing only on production automation for continuous production processes.

In addition national visionary scenarios are provided like in Germany for *Industrie 4.0* from the perspective of year 2025[27]. And whilst the German "Platform Industrie 4.0" continues to drive forward its activities - especially by increasing and broadening its communication efforts - a few future-orientated results are already available. First of all, the Reference Architecture Model for Industrie 4.0 should be taken into account[28] [29]. All these documents give important direction on the development of smart production based on increased connectivity, real-time capabilities, seamless process design and simulation, distributed big data collection and distributed advanced analytics.

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[25] *Factories of the Future 2020: Roadmap 2014-2020,* http://www.effra.eu/attachments/article/129/Factories%20of%20the%20Future%202020%20Roadmap.pdf.

[26] *A European Roadmap for Industrial Process Automation,* http://processit.eu/roadmap.

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ROADMAP for SMART PRODUCTION										
	2018		2019		2020		2021		2022	
Instant access to virtual dynamical factory										
Robust parameter and state update mechanisms for complex dynamic models.										
Platforms supporting multi functional views, e.g., dynamic, topological, steady-state.										
All purposes and multi-technology simulators with integration of computations, simulations and engineering data.										
Data management enable backtracking.										
Virtualisation of legacy systems.										
Computing architecture for large number of simultaneous instances of a virtual factory.										
Fast and robust virtualisation of the control system and its pairing with the virtual factory with seamless transition between the virtual and physical representations.										
Strategies for exchanging virtual representations as a natural part of achieving collaborative automation.										
Increased information transparency between field and ERP										
Integration of field devices with high-level systems addressing transparency including data compression, distributing computation and decision support, service descriptions and semantics.										
Services-Oriented Architecture at the field level enabling advanced properties and functions to ERP/ MES.										
Systems engineering approach to architectures and applications										
Automation in the cloud through loosely coupled sensors and systems.										
Real time sensing and networking in challenging environmets										
Open yet secure systems mechanisms for IoT devices										
Industrial-purpose sensor and tracking equipment with the adoption of low-cost technologies										
Energy management of sensor and actuator systems										
Production industry as an agile part of the Energy system										
Production flexibility through integration of control, business, ERP, cap and trade and maintenance systems.										
Automation and support systems to maximise overall plant efficiency while integrating into the larger context of societal functions.										
Management of critical Knowledge for maintenance decision support										
Transformation personnel knowledge to system knowledge										
Technologies to support specialised remote maintenance services.										
Technology for context awareness – only the information needed for the tasks and user.										
Ubiquitous self-diagnostic methods and techno-logies										
Automation service and function engineering										
Model based development of functionality for systems- of-systems including automatic code generation										
Verification tests for complete systems										
Engineering tools supporting: open simulator platforms, plant wide optimisation, control optimisation										
Interoperability of the virtual plant and component models at all development stages:										
Open simulator platform										
Dynamic component- based simulations										
Support for multi-domain and multi-physics simulations.										
Model configuration must be neutral, i.e., it should not be simulation tool-specific.										
Need for distributed simulation model configuration and usage, including version and access control.										
Simulation data visualisation										
Links from simulators to engineering tools.										
Support for validation and verification of simulation models										
Seamless simulation of production system at different levels within a product life-cycle										
Automation system for flexible distributed Production										
Principles and methods to automatically generate the requirement specifications for distribute automation systems.										
Methods for automatically generating cost-effective temporal solutions for the rapid replacement of production units and their respective roles										
Balancing of system security and Production flexibility										
Tools and methods for emerging technical approaches within production automation assuring system reliability, security and safety.										
Online hazard analysis tools.										
Detection of tampered automation devices and services.										

Figure 22: Roadmap for Smart Production

Strategic thrusts Part B: Essential technologies

6 Semiconductor Manufacturing, Technology, Equipment and Materials

6.1 Objectives

Semiconductor technology is indispensable for meeting the challenges of the European society. The availability of in-Europe manufacturing is essential to supply Europe's electronic systems manufacturers with critical components. The European manufacturing position must be reinforced through leadership in processing know-how for all advanced technologies: advanced and beyond CMOS (More Moore, MM), heterogeneous integration (More than Moore, MtM) and System in Package (SiP). The complete European value chain in process technology, materials, equipment and manufacturing capability must be supported to realize next generations of devices meeting the needs expressed by the application roadmaps.

Grand Challenges are identified in this MASRIA 2017[30] that need specific attention and targeted collaborative actions at European level.

- For semiconductor process technology and integration: (i) advanced and distributed compute infrastructure and system performance scaling to support the growing need for abundant data processing, 5G and Internet of Things[31], (ii) devices and components at chip-level and SoC for the complex heterogeneous functionality essential to address the specialization for diverse application needs, (iii) advanced smart System-in-Package applications to deliver the functionality in the meeting the demanding specifications and boundary conditions of the applications.
- And – in line with the above challenges – the requirements for Equipment, Materials and Manufacturing to address the continuous need for specialization and advanced levels of equipment, unit processes, process integration and packaging with a strong technology-design-system-application interaction: (i) develop European know-how for advanced Equipment, Materials & Processes for sub-10nm semiconductor devices & systems manufacturing, (ii) strengthen European competitiveness by developing advanced More-than-Moore (MtM) Equipment, Material and Manufacturing solutions for front-end-of-line (FEOL) and back-end-of-line (BEOL) wafer processing and device assembly and Packaging (A&P), (iii) develop new fab manufacturing and appropriate E&M solutions that support flexible, agile and competitive semiconductor manufacturing in Europe and supply the worldwide market with correspondingly 'best-in-class' hardware and software products.

6.2 Strategy

Well-focused projects in the TRL 2 to 4 are needed as technology push enabling new applications. Extended projects will aim at Pilot lines with emphasis on TRL 4 to 8 delivering industry-compatible flexible and differentiating platforms for strategic demonstrations and for pushing manufacturing uptake. Technologies will drive the realization of industry roadmaps in MM, extending it to extreme and beyond CMOS nodes - and in MtM and SiP - including amongst others power electronics, III-V and 2D materials, RF technologies, integrated logic, photonics, 3D integration technologies, MEMS and sensor systems, interlinked with key application challenges. Special attention will be given to emerging technologies as they come along as well as to new developments in the

[30] See also the AENEAS AGENDA 2016 for more details and inspiration for projects: http://www.aeneas-office.eu/web/documents/ASA_2016.php.
[31] See also the "Rebooting Computing" initiative of IEEE: http://rebootingcomputing.ieee.org.

equipment and materials industry, in which Europe has a leading position. New flagship projects focused on employment of advanced multifunctional nanomaterials for new product development can be expected.

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

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

Promote the involvement of all actors in the value chain of process technology, materials and equipment, with application specific partners or cross-links to application specific projects. Complement Pilot Line projects (higher TRL) for the validation of new technologies and equipment with manufacturing science (typically lower TRL), mastering cost competitive semiconductor manufacturing in Europe including packaging and assembly. Goal is to develop new solutions, cost competency and business models that enable a high degree of manufacturing flexibility required by diversified products, while achieving sustainability targets (resource-efficiency and “green” manufacturing) without loss of productivity, cycle time, quality or yield performance at reduced production costs.

More Moore manufacturing will especially require innovative solutions to control the variability and reproducibility of leading-edge processes. A Productivity Aware Design (PAD) approach will focus on predictive maintenance, virtual metrology, factory simulation and scheduling, wafer handling automation and automated decision management. In addition attention should be given to Control System Architecture: predictive yield modelling, holistic risk and decision mastering (integrate control methods and tools and knowledge systems).

While some of these elements are essential for MtM also, specific focus areas here are: (i) cope with high volumes and high quality (for e.g. power semiconductors, sensors and MEMS devices) and (ii) enable flexible line management for high mix, and distributed manufacturing lines. It will also require adapting factory integration and control systems to adopt industrial internet principles to manufacturing environment in Europe.

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

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

6.3 Impact

The European semiconductor ecosystem employs approximately 250,000 people directly and is at the core of innovation and competitiveness in all major sectors of the economy. The overall value chain of equipment, materials, system integration, applications and services employs over 2,500,000 people in Europe. By launching new process and equipment technologies based on innovative materials, designs and concepts into pilot-lines, ECSEL projects will facilitate a strongly growing market share, increase employment and investments for innovative equipment, materials and for manufacturing of semiconductor devices and systems through European leadership positions in MM, MtM and SiP.

Europe's semiconductor manufacturing industry suppliers have a long history of successful mechanical engineering, tailor-made machinery, optical equipment, metrology, inspection and testing equipment, and chemical processing tools. In addition there are suppliers of raw materials, ancillary materials and substrate materials in Europe that successfully export their products to global markets. This history of success has made Europe a world leader in several domains, foremost in lithography, metrology and silicon substrates, but also in thermal processing, deposition, cleaning, wafer handling as well as wafer assembly and packaging. The semiconductor equipment and semiconductor materials sectors employ in Europe more than 100 thousand individuals, the majority of them in high education level jobs.

When considering the competitive situation of the European semiconductor process and integration technology, it needs to be seen in the overall perspective of the value chain. Whilst the manufacturing of electronic components, circuits and systems is under pressure, some European companies are able to keep a strong position in specific domains and there are opportunities for growth. The suppliers of process integration equipment and novel materials are evidently key partners in this path to growth, since Europe has a very strong tradition in this field. The further development of technologies for future generation computing, communication, and heterogeneous functionality will allow the European industrial players to grow their presence in the opportunity areas like automotive, healthcare, internet of things. It further links to other strengths in Europe on the system implementation and the software and service innovation. Furthermore, through a traditionally strong and advanced educational system, the R&D position in Europe throughout the whole stack of competences is remarkable. Europe's semiconductor manufacturing industry mainly serves electronics and system markets in which Europe already holds strong global industrial positions, for example, the automotive, aircraft manufacturing, power generation and medical/healthcare industries. Therefore, its semiconductor technology strengths are also in these domains, i.e. chip development and manufacturing in automotive, power, healthcare, security and safety. Ensuring the continuation of competitive manufacturing in Europe supported by a high level of excellence in manufacturing science and efficiency will enforce strong global industrial positions (security, automotive, aircraft manufacturing, power generation and medical/healthcare) and significantly contribute to safeguard our strategic independence in critical domains and secure tens of thousands of jobs directly or indirectly linked to the semiconductor manufacturing.

6.4 Cross references

Europe needs leadership throughout the value chain from process, materials and equipment to production of devices, systems and solutions and deployment of services to leverage Europe's strong differentiation potential and to drive its competitiveness.

System-Technology co-optimisation is key to all leading edge innovations. Specific actions include: Specification of technology and product roadmaps for the planning of future products, Advanced access to new technologies for prototyping, Cooperation on development of dedicated technologies, advanced access to testbeds and markets. The impact of technology choices on the application and vice versa is becoming very large and decisive in successful market adoption. This is true for all application fields but especially so where the communication, compute and sensing technology is key to deliver the expected (quality of) service or function, e.g. Industry, Automotive, Health. In this respect, one of the most important challenges ahead for Europe is the broad and deep implementation of IoT in the industry, together with so-called 'exponential technologies', jointly named "Industry 4.0". In order to meet the related challenges, we need to consider the integration of the whole system. Thus, we should not restrict our scope to semiconductor devices; instead, we need to combine research in all key domains of which the Industry 4.0 is composed and the importance of a consolidated effort cannot be overemphasized.

Collaboration with the design community: While there is traditionally a close link to the design community – Design - Technology co-optimisation is a well-known trend - these ties need to be further enforced. The number of technology options, each with its own challenges, explodes. Early and quantitative assessment of the gains, issues, and risks is key to maximize the value of this technology for a given application. Likewise, technology development faces the same challenges to deliver a technology that suits the purposes of designers. Specific focus areas include: building, sharing and incorporating physical models of components, device electrical characteristics, models of degradation effects, data on parameter variability and dispersion. In response there will be design solutions generated for process variability and process reliability, as well as for device in package integration with the modelling of thermal, mechanical and EMI effects. Use advanced SW tools with well-calibrated physical parameters of electro-thermal models for the identification of critical issues, and for the generation of new devices with optimized properties.

6.5 Roadmaps

6.5.1 Process Technology and Integration

Three Challenges in semiconductor process technology and integration are identified that need specific attention and targeted collaborative actions at European level: (i) advanced and distributed compute infrastructure and system performance scaling, (ii) devices and components at chip-level and SoC for the complex heterogeneous functionality, (iii) advanced smart System-in-Package applications.

For Challenge 1 the roadmap for process technology and device/system integration presents relatively clear timelines, although economic factors determine the speed of adoption in industrial manufacturing. Areas where the roadmaps are less clear (e.g. new compute paradigms) are not introduced here since timelines are too speculative now. For Challenge 2 and Challenge 3 the timeline of implementation of new technologies largely depend on the systems needs and roadmaps and will result from the interaction within application driven projects and testbed initiatives. All leading European industry and research actors align their activities with international roadmaps and timelines. Roadmap exercises are being conducted in various projects and communities like NEREID [32] and the recently announced IEEE IRDS [33] in which European academia, RTO's and industry participate. The European R&D priorities are to be planned in

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

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

synchronization with the global timeframes and developments, which are under continuous adaptation. The timelines below are high-level derivatives from these global evolutions.

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

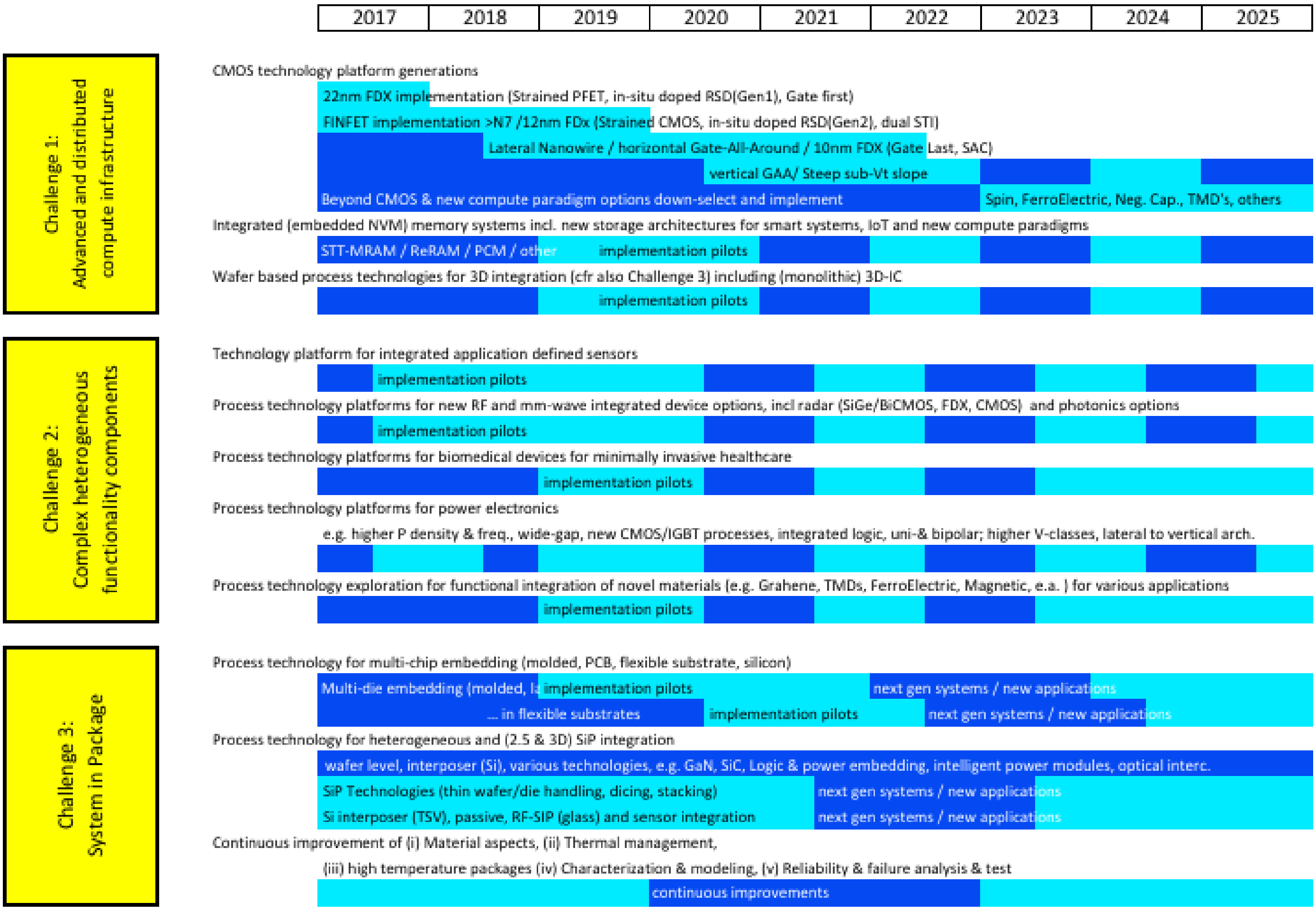

Figure 23: Roadmap Process Technology and Integration

6.5.2 Equipment, Materials and Manufacturing

<u>Grand Challenge 1: More Moore Equipment and Materials for sub-10nm technologies:</u> The sub-10nm patterning solutions to be developed in the Grand Challenge “More Moore Equipment and Materials for sub-10nm technologies” will need to be available two years ahead of the point in time at which advanced semiconductor manufacturers will start the high-volume IC manufacturing at the corresponding node.

<u>Grand Challenge 2: More-than-Moore Equipment and Materials:</u> The timing of new E&M solutions for the Grand Challenge ‘More-than-Moore’ should be derived from the schedules of the major European semiconductor manufacturers. Of course, also the updated More-than-Moore roadmap for devices and technologies need to be taken into consideration. The MtM roadmap outlines roadmaps for key future semiconductor domains, such as automotive, health care, safety and security, power, MEMS, image sensors, biochips, lighting etc. Fast implementation and adaptation

of these new device technologies will pave the way for the More-than-Moore technologies of tomorrow.

Grand Challenge 3: Manufacturing: New E&M solutions for the Grand Challenge “Manufacturing” should be developed according to the market needs defined in the More Moore and MtM roadmap and enhancing state-of-the-art manufacturing practices. Improving manufacturing efficiency, and enhancing yield and reliability are on-going tasks that need to be performed in accordance with the needs of the ‘More Moore’ and ‘More-than-Moore’ domains. Fundamentals of ‘manufacturing science’ will concern projects at rather low TRL levels (typically 3 to 5). In addition, implementation in Pilot Lines and full scale manufacturing lines will contemplate higher TRL level projects (typically 7 to 8). For most of the Manufacturing Science projects, the execution will be spread along medium to long term time span, though shorter term impact, such as improving uptime of equipment thanks to productivity aware design or the improvement of robustness of the manufacturing processes), will get due attention to enhance competitiveness.

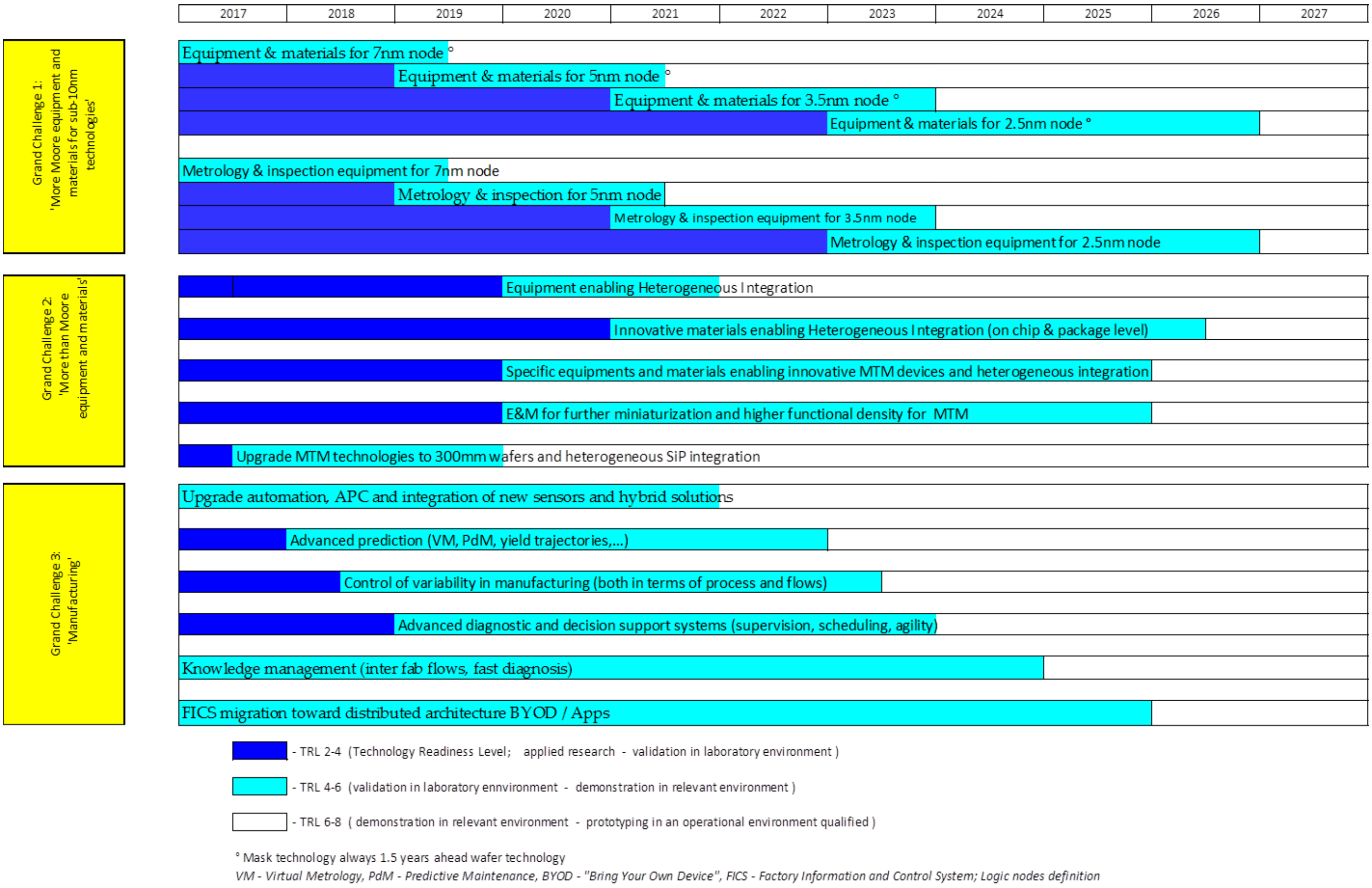

Figure 24: Roadmap Equipment, Materials and Manufacturing

7 Design Technology

7.1 Objectives

Effective design methods, tools and technologies are the way in which ideas and requirements are transformed into innovative, producible, and testable products, at whatever level in the value chain. They aim at increasing productivity, reducing development costs and time-to-market while ensuring the level of targeted requirements such as new functionalities, quality, performance, cost, energy efficiency, safety, security, and reliability. Thus, standards for interoperable solutions will be a priority to largely reach these goals and efficiently develop system and component designs.

Design methods, tools and technologies must establish the link between the ever-increasing technology push and the demand for new innovative products and services of ever-increasing complexity that are needed to fulfil societal needs. Design methods, tools and technologies cover the design flows required to enable the specification, concept engineering, architecture exploration, implementation, and verification of Electronic Components and Systems[34] (ECS). The design process embraces in addition to design flows and tools, libraries, IPs, process characteristics and methodologies including such to describe the system environment and use cases. It involves both hardware and software components, including their interaction and the interaction with the system environment, covering also integration into (cloud-based) services and ecosystems.

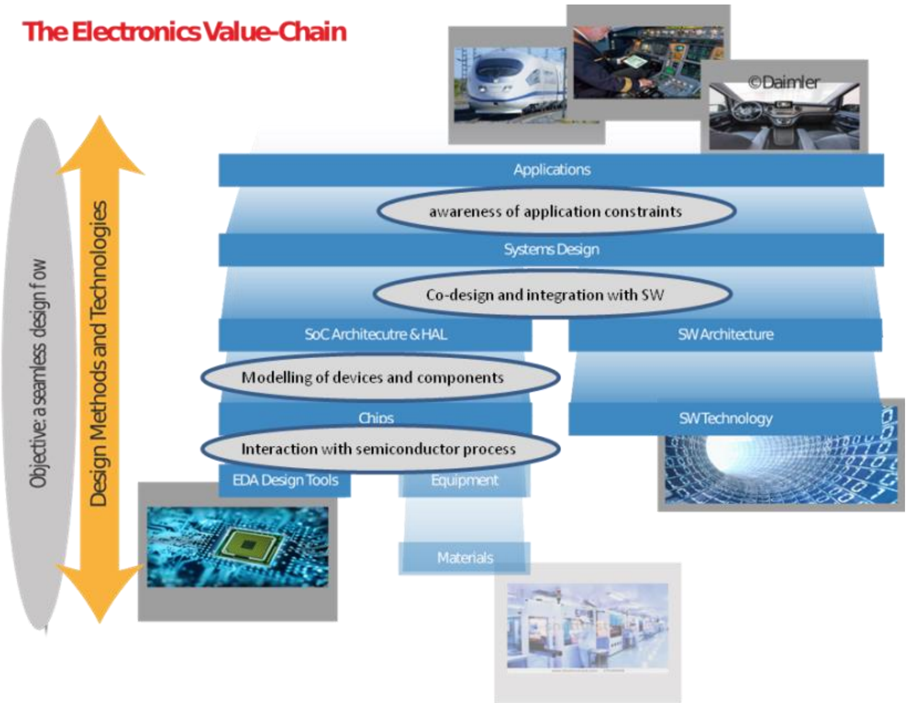

Figure 25: Design flow, methods and technologies cover the entire value chain, from semiconductor materials and processes to chip level and systems including the development of applications / platforms

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[34] The word "systems" is used in this context for the respective highest level of development which is targeted within the given part of the value chain. It may range from semiconductor device characteristics along chip or block level up to the level of complex products – such as aircrafts, cars, or complex lithography systems. While ECSEL has to take into account product level requirements for such complex products, it focuses on innovations in ECS for these, and design methods and technologies enabling their integration into the complete product.

7.2 Strategy

In the frame of ECSEL program, design technologies will focus to meet the following four challenges:

1) **Managing critical systems including safety, security and certification:** Aims at enabling seamless development methods and tools for critical systems, with a strong focus on safety and security analysis and certification. Major topics are modelling of critical systems, model-based design, V&V (verification & validation technologies, virtual platforms and simulation support for safe and secure, certifiable ECS. Mixed-criticality design, which is implementing systems combining functions with different safety levels, is an additional challenge.
2) **Managing complexity**: Aims at developing solutions for managing the design of complex ECS in time at affordable costs. It focuses on system design topics, architecture exploration and design, and the implementation process. It establishes and extends methods and associated tools needed to handle the ever increasing complexity of innovative ECS to increase design productivity.
3) **Managing diversity**: Aims at the development of design technologies to enable the design of complex smart systems and services incorporating heterogeneous devices and functions, including V&V in mixed disciplines like electrical, mechanical or optical.
4) **Managing multiple constraints**: Aims at developing design technologies considering various constraints (e.g. design for yield, robustness, reliability, safety), functional and non-functional (e.g. power, temperature, time, etc.) properties as well as constraints coming from the applications themselves. The cross-propagation of constraints among the different domains, nowadays involved in systems, is an important issue to be considered for system design.

These challenges are considered as high priority for the presently required increase of design efficiency, design ability and the respective competitiveness improvement. It is therefore recommended that a balance in the activities on low and high TRL should be sought.

7.3 Impact

A success in overcoming these challenges will lead to the development of systems, system-of-systems and products (incl. services) which are several times more powerful – and, from a design perspective, thus several times more complex with the need to ensure the safety and security requirements – than the current ones without increasing significantly time and development costs.

At system level, improving design and development efficiency as well as verification and validation speed will lead to improved product and service quality. This will be achieved thanks to the development and introduction of novel design flows, tools and methods. The expected impact on the following key performance indicators every three year is: 1) mastering by 100% the increase of systems complexity, 2) reducing by 20% design efforts and 3) reducing up to 50% cost and cycle time of product/system design.

On a larger scale, systems are evolving from single-owner designs to larger systems or even systems-of-systems, which communicate with each other, using internet or similar media, produced by multiple companies. Effective and standard-based design methods and technologies will cope with this paradigm shift and will allow for larger market share, higher competitiveness of European industry in all application sectors addressed by the MASRIA and contributing to increase employment in Europe.

7.4 Cross references

The design technologies provide the tools and methods enabling the design of the products (incl. services) required for all applications addressed in this MASRIA, described under “Smart everywhere”. They are also essential in the design of Cyber Physical Systems and Smart Systems Integration; hence, a strong interaction with these two technology areas is expected. Furthermore and in order to design secured systems, a strong interaction with the Safety and Security group is required. Finally, a particular interaction will be required with the Semiconductor Process, Equipment and Materials considering that the design performance, yield and robustness will be based on their inputs.

		Applications					Esssential Technologies			
Grand Challenges	**High Priority Research Areas**	Smart Mobility	Smart Societies	Smart Energy	Smart Health	Smart Production	Semiconductor Process, Equipment & Materials	Cyber Physical Systems	Systems Integration	Safety and Security
Managing Critical Systems, including Safety, Security and Certification	Modelling (Environment, multi domain, multi-dimensional, multi optimization)	X	X	X	X	X	(X)	X	X	X
	Model based design, V&V methodology and tools for complex, safe and secure ECS, incremental certification	X	(X)	X	X	(X)		X	X	X
	Virtual Platforms and Simulation of ECS	X	X	X	X	X		X	X	X
Managing complexity	Architecture (compose the system)	X	X	X	X	X		X	X	X
	System Design	X	X	X	X	X		X	X	X
	Overall design environment to ensure Design Productivity	X	(X)	(X)	(X)	X	X	X	X	X
Managing diversity	Multi-objective Optimization	X	X	X	X	X	X	X	X	(X)
	Modelling & Simulating in Heterogeneous Systems	X	X	X	X	X	X	X	X	(X)
	Ecosystem for processes, methods and tools for the cost efficient design along the whole value chain	X	(X)	(X)	(X)	X	(X)	X	X	X
	Integrating analog and digital designs and design methods	X	(X)	X			X	X	X	
	Connection of Digital and Physical World	X	X	X		X	X	X	X	
Managing multiple constraints	Ultra-low power HW/SW design Flows			(X)	X		X	X	X	X
	Efficient modelling, testing and analysis for dependable complex systems, considering physical effects	X	X	X	X	X	X	X	X	X
	Monitoring and Diagnosis methods and tools	X	X	X	X	X	X	X	X	X
	Building secure extendable or evolvable Systems	X	X	X		(X)	X	X	X	X
	Tackling of new technology nodes	X	X	X	X	X	X	X	X	(X)

Figure 26: Cross reference between challenges of Design chapter to the other chapters

7.5 Schedules/Roadmaps

7.5.1 Managing Critical Systems, including Safety, Security and Certification

Many new and innovative ECS exhibit an ever increasing level of automation, an ever increasing capability to cooperate with other technical systems and with humans, and an increasing level of (semi-) autonomous decision making capabilities, in order to fulfil their intended function. Building these systems, and guaranteeing their safety, security and certification, requires innovative technologies in the areas of modelling (systems, their environment, as well as use-cases, scenarios, etc.), model-based design, V&V technologies, virtual platforms and simulation support for safe and secure, certifiable ECS (see *Figure 27*).

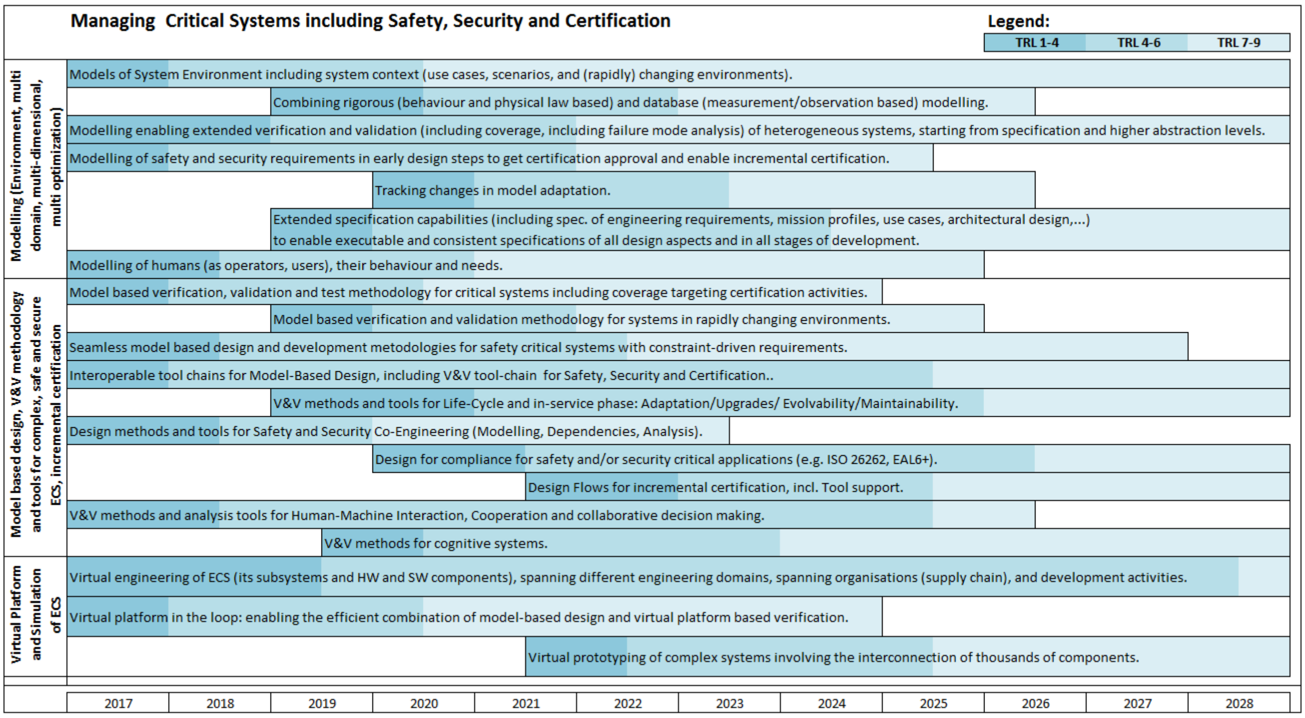

Figure 27: Roadmap for Managing Critical Systems, including Safety, Security and Certification

7.5.2 Managing Complexity

With increasing role of electronics systems and especially under the influence of connected systems, the complexity of new and innovative ECS increases constantly. Better and new methods and tools are needed to handle this new complexity and enable development and design of such complex systems in order to fulfil all functional requirements, get cost-effective solutions thanks to high productivity. This challenge focuses on architecture principles, system design topics, HW/SW co-design and the overall development process in order to achieve these goals (see *Figure 28*).

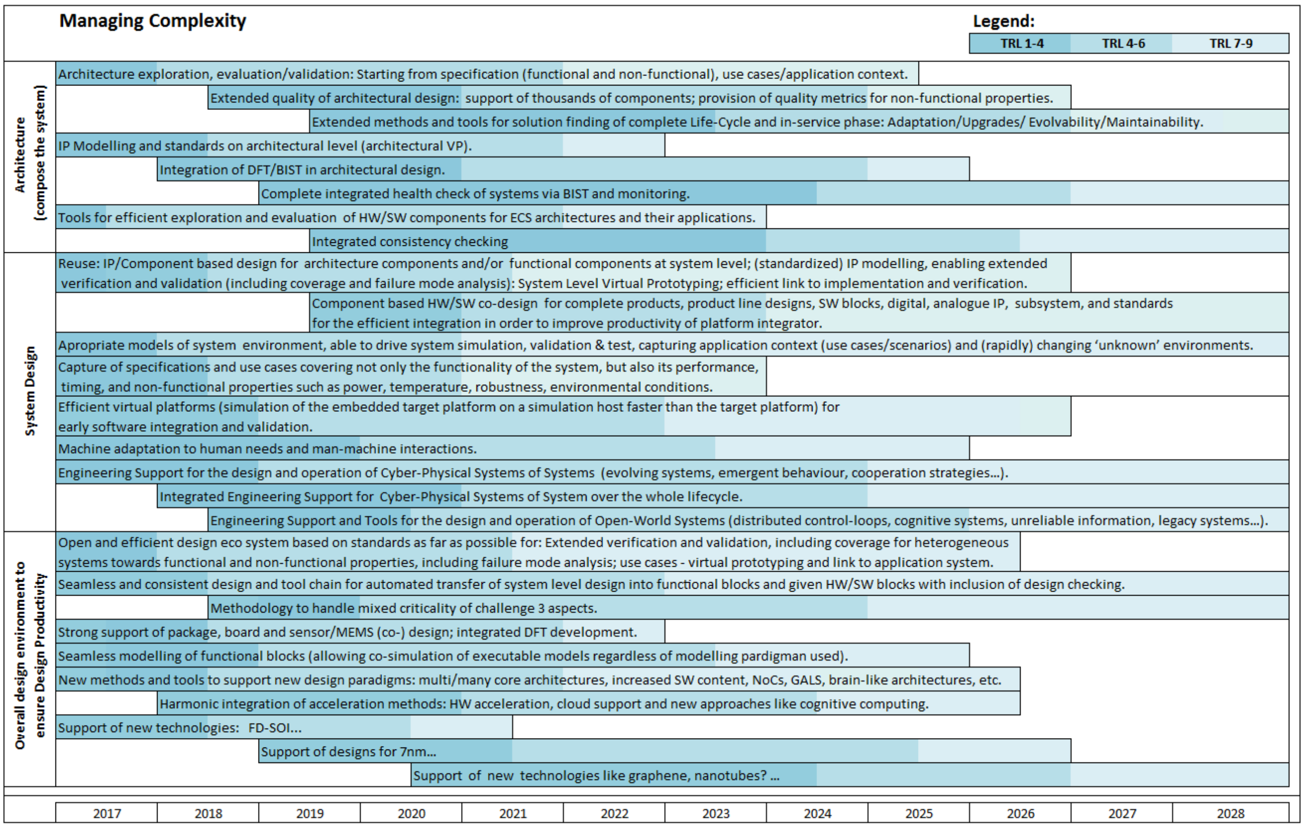

Figure 28: Roadmap for Managing Complexity

7.5.3 Managing Diversity

In the ECSEL context a wide range of applications have to be supported. With growing diversity of today's heterogeneous systems/designs requiring integration of analog-mixed signal, digital sensors, mems, actuators/power devices, domains of physics as for example mechanical and fluidic aspects that have to be considered at system level, and embedded software. This design diversity is enormous. It requires multi-objective optimization of systems, components and products based on heterogeneous modelling and simulation tools. Last but not least, a connection of the digital and physical world is needed (see *Figure 29*).

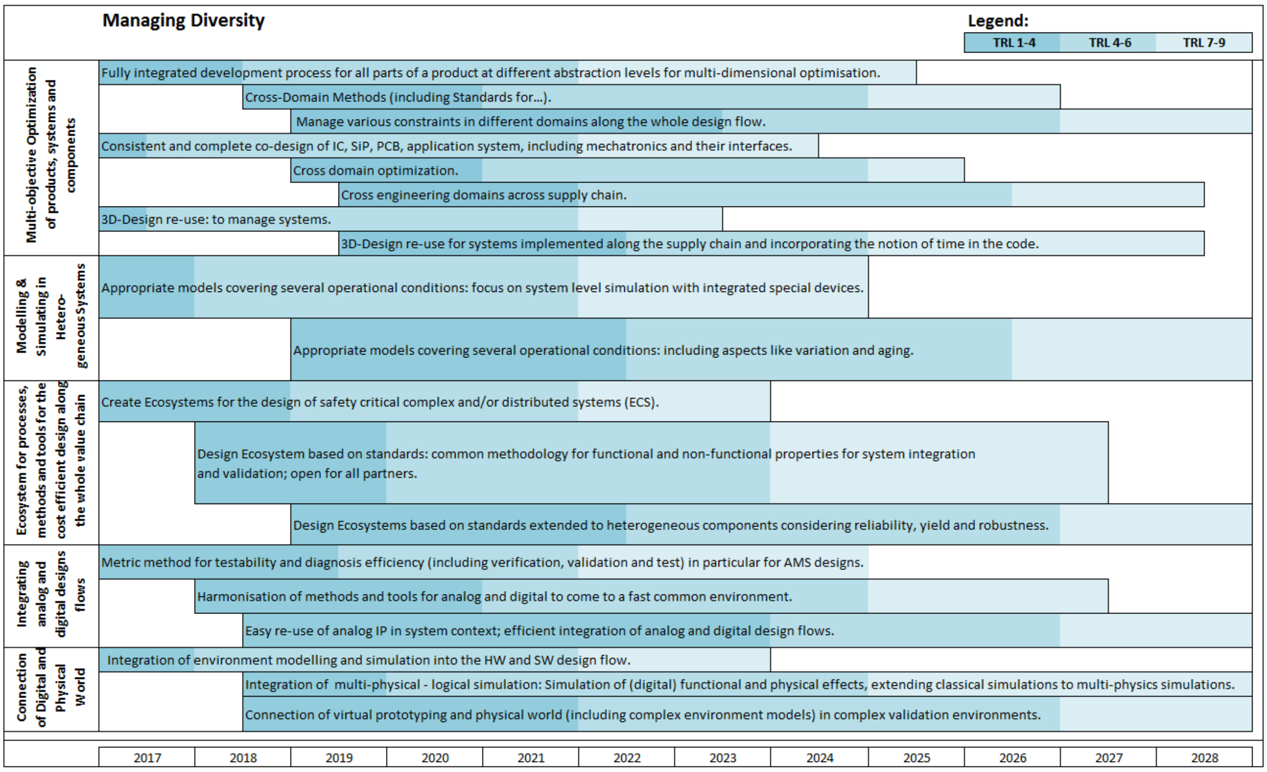

Figure 29: Roadmap for Managing Diversity

7.5.4 Managing Multiple Constraints

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

To manage multiple constraints will require an integration of methods, tools and flows for analysing and optimizing multiple constrains in a single holistic approach. This includes ultra-low power design, monitoring and diagnosis methods and tools, building secure extendable or evolvable systems, tackling of new technology nodes and efficient methodologies for reliability and robustness in highly complex systems including modelling, test and analysis, considering variability and degradation (see *Figure 30*).

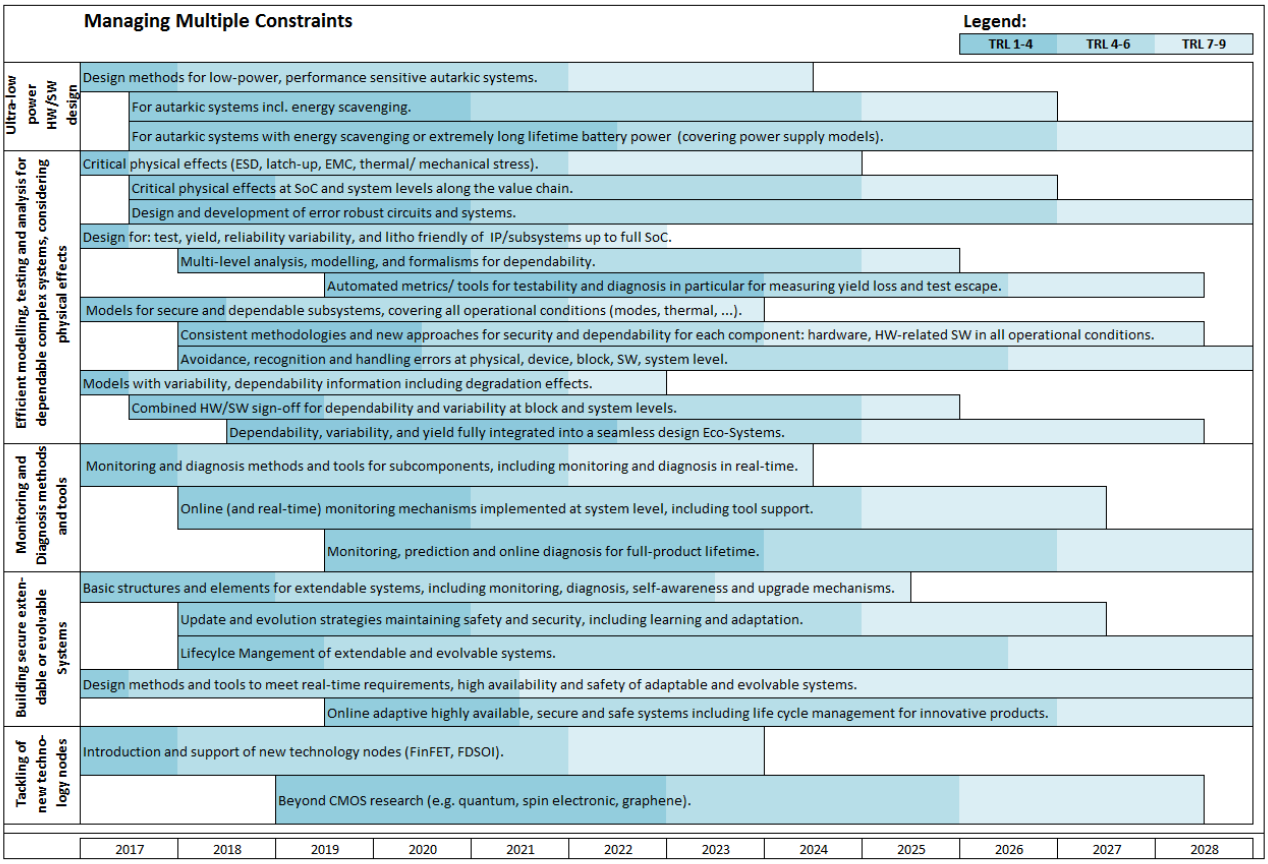

Figure 30: Roadmap for Managing Multiple Constraints

8 Cyber-Physical Systems

Cyber-Physical Systems (CPS) are electronic systems, components and software that are tightly interacting with physical systems and their environment: their embedded intelligence provides capabilities to sense, monitor, analyse and control physical devices, components and processes in various fields of application, such as mobility, aerospace, healthcare, food, agriculture and production systems. Their ability to connect and interoperate, through all kinds of networks and protocols (including the Internet, wired, wireless communications), allows them to coordinate and optimize high-level functionalities. [35]

They offer exponentially growing opportunities for many application sectors and businesses. The global market of Digital Technology is estimated at USD 3,300 billion, corresponding to around 50 million jobs. Europe's position is characterised by a strong presence in software and services, representing 8.9 million jobs.[36]

Although CPS, as complete systems, are built to fulfil certain applications, many technological topics and issues in these systems are common to other research areas (application independent) and as such, CPS can be regarded as enabling technologies. They also closely work with and within infrastructures, evolving concretely the way we design and use the traditional Embedded Systems (ES).

Architecture, engineering and design approaches have to be radically rethought under the requirements and constraints of the CPS-based Industrial Systems, especially when key issues on (near) real-time interaction, complexity, security and safety, cross-layer collaboration, energy efficiency, support to system of systems adaptive evolution, heterogeneity, interoperability, scalability etc. are coming into play. For example, safety has to be guaranteed for the growing number of driver assistance functions in cars; interoperability is needed between the various subsystems involved in building management; adaptive evolution has to be possible even for long lifetime systems with certification requirements such as aircrafts; scalability is key for the deployment of innovative production management systems involving thousands of sensors; privacy must be ensured in healthcare systems, involving data exchanges between subsystems, from device to information system; energy efficiency is a common concern for many domains; resilience to cyber-attacks is a challenge shared by most of them.

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[35] In our view, CPS includes the "Internet of Things" (IOT) .While Internet of Things mainly deals with communication of sensor, actuators, devices and the cloud CPS, CPS is more general and ".focuses instead on the fundamental intellectual problem of conjoining the engineering traditions of the cyber and the physical worlds" (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4435108/). For a more comprehensive description of key characteristics of CPS see https://s3.amazonaws.com/nist-sgcps/cpspwg/files/pwgglobal/CPS_PWG_Framework_for_Cyber_Physical_Systems_Release_1_0Final.pdf).

[36] ITEA/ARTEMISIA High-level vision 2030, see https://artemis-ia.eu/publication/download/907-vision-2030.pdf.

8.1 Objectives

For the coming period (2017-2020), the following priority targets are selected to guide the ES/CPS R&D&I programmes/projects with the purpose of having greater impact on the European competiveness, to reduce the time to market, and to strengthen the European stakeholder's leadership positions in the new 'digital transformation age':

1) Expand strong research and innovation potential while **overcoming fragmentation** in the European supply base, optimising investments and use of resources to yield multi-domain and reusable smart products and related services.
2) Exploit the growing **'Internet Economy'** opportunities**,** where human and machines[37] interact & collaborate to provide a myriad of new services and businesses responding to the strong demand of the **'Always Connected Society',** based on **digital platforms and interoperable eco-systems** providing large streams of data and information, enabling acceleration of innovation and the creation of new business models**.**
3) **Master the complexity, ensuring safety and security** while reducing the cost of utilizing powerful software intensive products/systems, encompassing System of Systems engineering and multi-disciplinary approaches, leveraging the potential of new information and communication networking techniques (softwarisation), data analytics, cloud, and enabling the development of dependable[2] and robust, cognitive and collaborative autonomous systems.
4) Enable a **more agile and shorter development cycle** through the adoption of design by composition, correct-by-construction principles and innovative architectures and verification methods, also suitable for **dependable[38] solutions** ensuring for users a high level of trust, confidence and privacy.
5) Provide support for related **Certification and Standardization Activities as well as for Education & Training.**

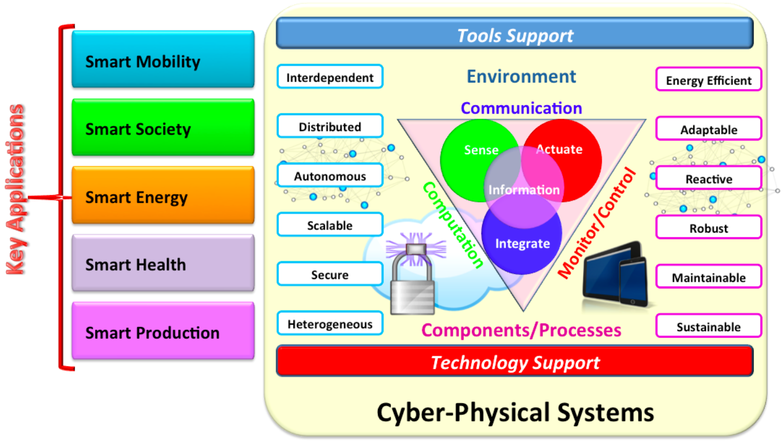

Figure 31: CPS platforms accomplishing ultimate functionalities and serving key application areas[39]

[37] Including M2M.
[38] Dependability includes: reliability, maintainability, resilience, safety, trust and security requirements.
[39] Smart production includes discrete manufacturing, process industries as well as the production of food by smart farming.

8.2 Strategy

To reach the above-mentioned objectives, the strategy and its implementation are built on:

- A **cross-domain sharing of technologies and research**: Expand the technology developments to address societal challenges through interoperable applications platforms and innovation ecosystems in smart cities, grids, buildings/homes, mobility and transportation, security of citizens, farming, production, healthcare and ambient assisted living, water and waste treatment, by addressing technological needs across these sectors and favouring the cross-fertilization and consolidation of R&D&I investments from mass market to safety- and mission critical systems.
- The vision of **'virtual vertical integration'** [40] that encourages market leaders to define the conditions for successful business innovation building on emerging technological developments, and vice versa, to coordinate technological **platform developments** (hardware and manufacturing to system design and software engineering) that should become recognized de-facto standards. On an organizational level, the horizontally specialized European industry faces a critical situation in this competition, unless vertical ecosystems emerge. Based on this assumption, the ECSEL CPS Programmes thrust pushes for contributing to and embracing standards, complementarity of the actors and solutions, scalability and interoperability.
- **A programme approach, with particular emphasis on developing interoperable platforms, using complementary instruments:** The emergence of the hyper-connectivity of ES, up to the current CPS era, faces long term challenges on both scientific and technical levels. There is an urge for disruptive technologies for: design processes, programming environments and methodologies, and to let these emerge through a phased research and development programme that includes:
  - i) **Focused projects**: a suite of projects to embrace both technological and application oriented development. They should typically span along TRL 3 to 5 and TRL 4 to 6 or higher
  - ii) Larger **'Think Big'** projects that act as umbrella for suite of projects aiming in the same direction and building upon each other (not necessarily all of them being funded in ECSEL) and promoting cross domain interoperability and the creation of recognized platforms. In addition to research and development, they encompass the user's concerns in particular those related to social acceptance of CPS applications, privacy and trust, safety, ethical and legal issues. Such projects should:
    - (1) Have a European dimension by combining R&D efforts across Europe,
    - (2) Build on existing assets, to bring concrete results to the market through 'infrastructures'/platforms for deployment testing.
    - (3) Address topics relevant to the competitiveness and future positioning of Europe.

The proposed **Programmes** for the strategy implementation of CPS evolution and market uptake, are structured along the following strategic axes:

1) **Principles, architectures and models for dependable**[41] **CPS** to define and develop global interoperable, distributed and certifiable CPS architectures, for the development of complex

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[40] such as GAFA: Google, Apple, Facebook, Amazon. More could be found at : http://www.supplymanagement.com/news/2013/virtual-vertical-integration-is-the-future-of-supply-chain.

[41] In systems engineering, dependability is a measure of a system's availability, reliability, and its maintainability, and maintenance support performance, and, in some cases, other characteristics such as durability, safety and security (https://en.wikipedia.org/wiki/Dependability).

monitoring and control strategies for smart applications including the realisation of dependable systems also from un-trustable, unreliable or partially unknown (grey box) sub-systems.

2) **Enabling technologies for autonomous, adaptive and cooperative CPS** for the efficient use of resources, for the seamless integration of computational and physical components for the resilience of systems, and for the global optimization of applications, all in a dynamic, enabling smart cooperation in an optimized manner.
3) **Computing Platforms including hardware, software and communication** to address the challenges of resource and energy efficiency, interoperability, security, reliability, complexity and safety of the multiple and various computing systems (covering the "Internet of Things" (IoT) from deeply embedded sensor/actuator to mobile, industrial, embedded controls, edge-computing, servers, data centres, and HPC systems, up to building of system of systems), their computing heterogeneous (hardware), distributed (firmware) and operating systems, and the corresponding software stack. They should facilitate life-cycle support, validation, verification and certification during the application life time.
4) **Digital Platform as usable references solutions combining the previous 3 topics.** Digital Platforms consist of supporting infrastructure, i.e. hardware infrastructure with software services, for which interoperability is well defined and understood. Cloud services, API architectures, open-source strategies, mobile development platforms and Internet of Things are some of the ingredients from which Digital Platforms are built. Digital Platforms are the enablers for the rapid digitisation of industry.

8.2.1 Principles, architectures and models for dependable CPS

In order to reduce the effort for establishing the desired interoperability of diverse products and be able to take full advantage of the economies of scale, developing cross-domain generic principles for embedded systems engineering and smart systems integration are[42] a technological and economic necessity. These framework architectures need to be supported by a pool of **industry standards, policies and best practice documents** to further stimulate the ubiquitous mass adoption in various markets as standards play an important role in interoperability and practical acceptance. Moreover, reference architectures should definitely aim at having more effective validation, verification and, most of all, certification processes. The key challenges are:

1) **Model driven engineering.** Model-based design methods and tools have been more and more established in industrial practice in recent years, at least for 'traditional' embedded systems. These methods must be enriched to allow multi-domain, multi-dimensional and multi-objective specification and modelling. The methodology must support (semantic) integration of heterogeneous models and also support re-use of models on different levels of the design process, i.e. to allow for usage of the same components (e.g. sensors) in different systems, for system variants, as well as for evolution of systems (i.e. the adaptation and integration of new or modified components and functionality). Closely related are the usage of models for certification as well as the development of model-based combined safety and security development processes. These methods and processes have to be supported by appropriate development tools, including tools for model management, integration of models from different domains and incorporation of legacy systems.
2) **Systems of systems (SoS).** Future CPS will be required to work in concert to provide their functionality. In fields like smart home, smart mobility, smart cities and smart factories a multitude of interconnected devices and systems have to work towards common goals besides their own objectives. While in the closed world embedded systems typically need to satisfy

[42] See also chapter „Smart Systems Integration".

real- time, robustness and fault tolerance requirements, additional flexibility, coping with variable latency and bandwidth and security requirements are imposed by open access. Moreover, we expect that future CPS with stringent real-time/safety requirements will be further augmented with distributed intelligence (e.g. in the cloud) and with other CPS (“Systems of Cyber-Physical Systems”). Such a high level of openness should not compromise safety- and security requirements. Semantic technologies are needed to support the flexible integration of systems in unforeseen scenarios. Comprehensive process and tool integration and validation frameworks are also needed to support efficient inter-discipline collaboration for global optimisation of CPS solutions.

3) **Reference Architectures** for safe and secure CPSs provide common functionalities that can be reused by a multitude of applications in several application domains. It is therefore necessary to develop principles, programming paradigms and tools, reference architectures including hardware, software and communication, design patterns, component-based and code generation to match HW/SW co-design in a variety of application domains. This should cover computing and communication features in local (multi-many core systems) as well as distributed, heterogeneous and open systems. They should also provide for robust scalable interoperability solutions integrated with the environment and mechanisms for efficient reuse, security (including cyber) and composability.
4) **Multi-/Many-core systems** Multi/many-core processors have now emerged, taking benefit of capabilities offered by the Moore’s law. Multicore processors are in many systems including personal computers and many-core are finding their own markets (data centres, image processing, etc). Beyond the programming efficiency issue of such architectures (going beyond von Neumann model habits) whose tools are still more or less in their infancy, their usage in CPS brings opportunities and challenges. For instance, these processors being not designed for real-time systems, they target best effort performance rather than predictability and ability to cope with strict time deadlines. New computing architectures, designed from the start with predictability in mind could really help the emergence of trustable systems for cyber-physical applications. IOT will foster the usage of heterogeneous multicore architectures still poorly addressed at software level (OS, compilers, tools).
5) **Dependability ‘by design’, and enabling certification** (against e.g. ISO26262 in automotive, DO-178/C in aeronautics and Common Criteria) of mixed critical systems in highly complex and non-deterministic environments at affordable costs. This must be extended from the design phase to operation (particularly in case of adaptive systems, were components and communication links appear and disappear or evolve). Exploring the usage of new testing methods and formal methods throughout the lifecycle. Ensuring a complete secure end-to-end protection of the hardware components, data and SW-programs, during computation and communication for enforcing more security and privacy even in open systems. Developing **resistance/resilience to external cyber-attacks** and internal system failures by mitigation and continuity /recovery strategies (self-healing). Building dependable systems from un-trustable, unreliable or partially unknown (grey box) sub-systems.
6) Answering the **fundamental challenges in CPS design** that arise from their dual cyber/physical nature, their multi-scale spatial-temporal nature, and the inherent uncertainty in the actions of the environment. Integrating the discrete mathematics of the cyber, with the continuous mathematics of the physical, the time-driven mathematics of the physical with the event-driven mathematics of the cyber, with the stochastic mathematics of the sensors, actuators and the environment. Reconciling the heterogeneous lifecycle of the physical- and the cyber.

8.2.2 Enabling technologies for autonomous, adaptive and cooperative CPS

Structural Integration and Behavioural Collaboration are major goals especially for a domain relative new to IT technologies and their rapid evolution pace. A digitalization of the industrial environment based on CPS-technologies has been proven to be an innovation backbone at Internet scale, and are finding their way in the future industrial internet of things. CPS need to tackle the following common issues and challenges:

1) **Safe and robust perception of environment**, dealing with the complexity and the dynamic changes and variability of the real world and with arbitrary complex situations and scenarios in real-time. Local data processing and recognition, sensor data fusion and the combination of several sensor modalities in order to deal with increasing complexity and robustness of HW/SW systems. Integrating new approaches (Soft computing, Bayesian, deep learning,…) with traditional ones for data analysis. Assessing application-specific robustness using appropriate V&V&T methods.
2) **Continuously evolving, systems**, **learning and adaptive behaviour** possibly inspired from biological systems (e.g. morphogenetic behaviour, digital tectonics, multimodal interaction, graceful degradation, etc.). Designing systems that are able to adapt themselves to changing environments and learn to understand and cope with complex situations in a safe and secure way.. As for perception, novel analysis and testing methods are needed to verify that learning and adaptive systems are sufficiently safe.
3) **Optimal control using autonomous CPS:** Efficient use of resources (power, computing, communication, development efforts and resources), optimization of global application performance and life-cycle costs enabling the development of intelligent, autonomous agents, despite limited accuracy/reliability in sensing and actuation, limited computational resources, and limited reaction time. As a consequence of this intelligence, such agents should be able to self-diagnose, self-reconfigure, self-repair and self-maintain in order to insure the needed failure tolerance and a proper performance level according to their global status.
4) **Reliable and trustable decision making, mission and action planning** for safety-related autonomous CPS/SoS that provide stability, safety, security in dynamically evolving system-of-systems, enable V&V&T and certification in reasonable time and cost. Supporting the interconnection of deterministic systems to highly non-deterministic. Detecting and tolerating unreliable constituting subsystems in open SoS.
5) **Human-machine interaction** requires several issues to be solved such as understanding and informing humans about the system intents as well as the development of new approaches, solutions, technologies using networked environments to enhance the ‘human-in-the-loop’ approach.
6) **Data Analytics for decision support** to realize further system optimization, including data analytics in the loop (streaming analytics, distributed analytics, HPC in the loop). Data analytics capabilities are specially challenging in critical heterogeneous co-operative systems, or in situations when connectivity is not always stable.
7) Appropriate **advanced methods and techniques for validation & verification, qualification and certification** of autonomous, adaptive, cooperative systems, including e.g. simulation and scenario based techniques to assess coverage of sensing, perception, decision making and action planning, and algorithms for optimal control.

8.2.3 Computing Platforms including hardware, software and communication

Cyber-Physical systems encompass a large range of computing devices and must integrate innovations in order to cope with the user's needs and real world requirements, such as hard real-time constraints, dependability), energy management, efficient data access and storage, dynamic reconfiguration, fault tolerance, easy application deployment and maintenance. Their connectivity will enable functions and functionalities to be distributed at all level of the CPS, like e.g. distributed analytics and local automation. Such platforms should allow the seamless integration of the various computing platforms to Systems-of-Systems. The key challenges are:

1) **Coping with the complexity of heterogeneous, distributed computing elements**. Ensuring the correctness and efficiency of complex heterogeneous distributed systems will be a major challenge, especially concerning the CPS requirements related to real-time, security, resilience and scalability. A particular challenge is parallelism (and multi-or many core computing modules), the systems will be composed of heterogeneous computing resources. Tasks will move from core to core depending on their loads, and some of them will be done by specific accelerators, more efficient than general purpose processors. In CPS, task can even be distributed onto different computing elements that can be physically distant. The ever increasing complexity requires new engineering methodologies and tools enabling drastically reduced efforts spent on system design and its engineering. These methodologies and tools also need to address the integration with existing legacy technologies and the migration from legacy systems to distributed computing platforms, thus enabling system lifecycle support.
2) **Energy efficiency:** Avoiding unnecessary data communications (e.g. by processing data to extract the useful information where it is captured), pushing for new innovative architectures and protocols. Making best use of new silicon technologies. Energy aware operating systems and middleware, data placement and retrieving. Energy-management on a system level, where application development and so on will require to harmoniously cooperate in order to further increase energy efficiency. Solutions cover **new tools and techniques,** real-time heterogeneous parallel processor, new memory architectures and chains, the development of parallel oriented programming languages and novel design methods, as well as new software architectures and setting up respective education.
3) **Techniques for continuously monitoring the performance** of the CPS should be designed in order to assess the dependability of the whole system through V&V&C. The security of data and the global integrity of a CPS are also of paramount importance.
4) Development of specific **accelerators for CPS functions**, like real-time data analytics (streaming analytics), cognitive functions (deep neural networks), cryptology or data security functions, etc.

8.2.4 Digital Platforms

Digital Platforms allow for the establishment of ecosystem and new business models by using external resources outside of the CPS. Challenges are interoperability and connectivity of devices, sensors and actuators, testing validation and certification of devices and services, Distributed Digital Platform architecture and scalability, Secure IT/cloud solutions and services, IT interoperability, Design technologies and user-centric design. The Digital Platforms will become data rich which means that they will enable new services and business models requiring data analytics techniques as process mining, deep learning visualization etc. Digital Platforms will address the following research challenges:

1) **Models of Cyber-Physical Systems** comprise models of the environment. Such models will need to take a closer look at the interface between the analogue and the digital world, since the state of the art in this area still leaves many issues open. For example, control theory needs to take a closer look at the implications of discretisation.

2) In the future the Cyber Physical System research should focus on **building services in smart spaces based on the capabilities of CPS** and promoting the interoperability of CPS as objects or nodes in Internet. The research is taking the direction of interoperability, development in semantic web, open data and linked data.
3) To really benefit from the added value of networking (similarly as stated in Metcalfe's law), the approach requires a **common infrastructure in addition to M2M solution islands** as well as a [global] systems for giving Things digital identities, the addressing of resolution services and support for managing the information. These issues are analogous to the Internet and should be handled in an open way so that smart services can be created and also innovated. This should addressed in collaboration with similar EU initiatives dealing with the "Internet of Things".
4) It would be futile trying to tackle the complexity challenge with a pure bottom-up development approach. In order to be competitive we have to establish **generic reference architectures and engineering platforms** on all relevant implementation levels to meet the development requirements of future Cyber-Physical Systems.
5) **Separation of concerns**: to increase the productivity and bring in more user centric design, the platform based approach, allows Platform developers concentrate on platform development and the users of the platform can invest their resources in providing added value at a higher layer.
6) **Provision of common services**: so that the platform provides common services which are required by most of the applications that will be realised on that platform
7) **Efficient reuse and composability**: a platform that follows a sound architecture should enable the creation of new products by composing them from a library of pre-validated building blocks. Such platforms such be established as a (de-facto) standard, as they only provide real value they are widely used. Proper strategies for establishing a successful platform have to be considered right from the very beginning.

8.3 Impact

The CPS results will deliver cross-domain solutions with reduced time-to-market and improved trustability, yielding significant economic results and growth in sectors critical to Europe's economy and competiveness **and drive innovation to cope with the 'new digital transformation' of Europe.** This should lead to a "virtual verticalisation" of the European industry to make it competitive to the big vertical non-European companies. The expected impacts of ECSEL CPS Programmes are:

1) Enabling **new business models and new services** through digitalisation and by exploiting digital CPS platform capabilities, addressing existing and new market potential.
2) **Create greater market opportunities and access greater market share** through new functional and new-functional properties enabled by the use of CPS technologies
3) **Exploiting the benefits of efficient connectivity and ubiquity of CPS as** the neural system of society in order to address European societal challenges by Smart-X applications (cities, mobility, spaces, health, grid, farming, production) through development and deployment of scalable, trusted, reliable, secure, privacy-aware and safe technological solutions
4) **Exploiting CPS technologies for the efficient use of resources** (energy, materials, and manufacturing time) through integration, analysis, collaboration, optimization, communication, and control.
5) **Mastering complexity while reducing the total cost of ownership, the global power consumption of** the systems and increasing the performance, reliability and security.
6) **Create Knowledge** through development of new designs, Verification & Validation & Testing (V&V&T) as well as Certification (V&V&C), methods and tools for CPS integration and deployment, for various application domains based on technology market roadmaps in multiple

time-scales, particularly for the safety-critical high reliability and real-time secure applications, while valorising the already available know-how.

7) **Enable continuous evolution and innovation** of pre-existing large scale CPS and facilitate smooth transition and integration with legacy systems.

8.4 Cross references

Societal Challenges are the key drivers for innovation in CPS. CPS technology has an impact on all application contexts of ECSEL as developed above: Smart Mobility, Smart Societies, Smart Energy, Smart Health, Smart Production. It also leverages the four other essential capabilities: Semiconductor Process, Equipment and Materials, System Integration, and especially Design Technologies, with which it has a number of topics in common.

8.5 Schedules / Roadmaps

All topics may be started in the call 2016; results are expected to be provided for:

1	Architectures principles and Models for safe and Secure CPS	Short Term	Medium Term	Longer Term
1.1	Model-Driven Engineering			
1.2	System of Systems			
1.3	Reference Architectures			
1.4	Multi-/manycore systems			
1.5	Dependability by design and enabling certification, resistance/resilience to external cyber-attacks			
1.6	Answering to the fundamental challenges in CPS design			
2	Enabling technologies for autonomous, adaptive and cooperative CPS	Short Term	Medium Term	Longer Term
2.1	Safe and Robust perception of the environment			
2.2	Continuously evolving, systems, learning and adaptive behaviour			
2.3	Optimal control using autonomous CPS			
2.4	Reliable and trustable decision making, mission and action planning			
2.5	Human-machine interaction			
2.6	Data Analytics for decision support			
2.7	Advanced methods and techniques for validation & verification, qualification and certification			
3	Computing Platforms including HW, SW and communication	Short Term	Medium Term	Longer Term
3.1	Coping with the complexity of heterogeneous, distributed computing elements.			
3.2	Energy efficiency			
3.3.	Techniques for continuously monitoring the performance			
3.4	Accelerators for CPS functions			
4	Digital Platforms	Short Term	Medium Term	Longer Term
4.1	Models of Cyber-Physical Systems			
4.2	Building services in smart spaces based on the capabilities of CPS			
4.3	Common infrastructure in addition to M2M solution islands			
4.4	Reference architectures and engineering platforms			
4.5	Separation of concerns			
4.6	Provision of common services			
4.7	Efficient reuse and composability			

Figure 32: Short term 3 to 5 year, (b) Medium (5 to 7) or (c) Longer term (beyond 7)
The colours are related to the TRLs: Low TRL: 3 to 5 High TRL: 4 to 7

9 Smart Systems Integration

Smart Systems Integration (SSI) is one of the essential capabilities required to maintain and to improve the competitiveness of European industry in the application domains of ECSEL. Although, in practice, SSI is often geared towards specific applications, the materials, technologies and manufacturing processes that form part of this domain are generic. SSI is hence an enabling technology in the area of Electronic Components and Systems (ECS) that needs to be developed further through research, development and innovation (R&D&I) in order to bridge the gap between technology and application and to move innovations into products and markets. Integration is referring to both the integration of the various components in order to create a Smart System, and to the integration of the Smart System into its application environment.

9.1 Objectives

The objective of the proposed R&D&I activities is to consolidate and to extend the present world leadership of European Smart Systems companies and to leverage progress in SSI for innovations on the technology and application level.

Smart Systems (*Figure 33*) are defined as (multi-)sensor and actuator-based devices, and can either be stand-alone systems or part of more complex systems of systems. This means that Smart Systems can be incorporated in IoT solutions and/or in Cyber Physical Systems (CPS) for which they will provide the decisive intelligent HW functionalities.

Smart Systems …

- … are able to describe, diagnose and qualify their environment in a given complex situation.
- … are capable of making predictions, to come to decisions and to take actions.
- … mutually address and identify each other.
- … are networked, autonomous and as small as possible to enable the respective application.
- … integrate multiple Key Enabling Technologies.

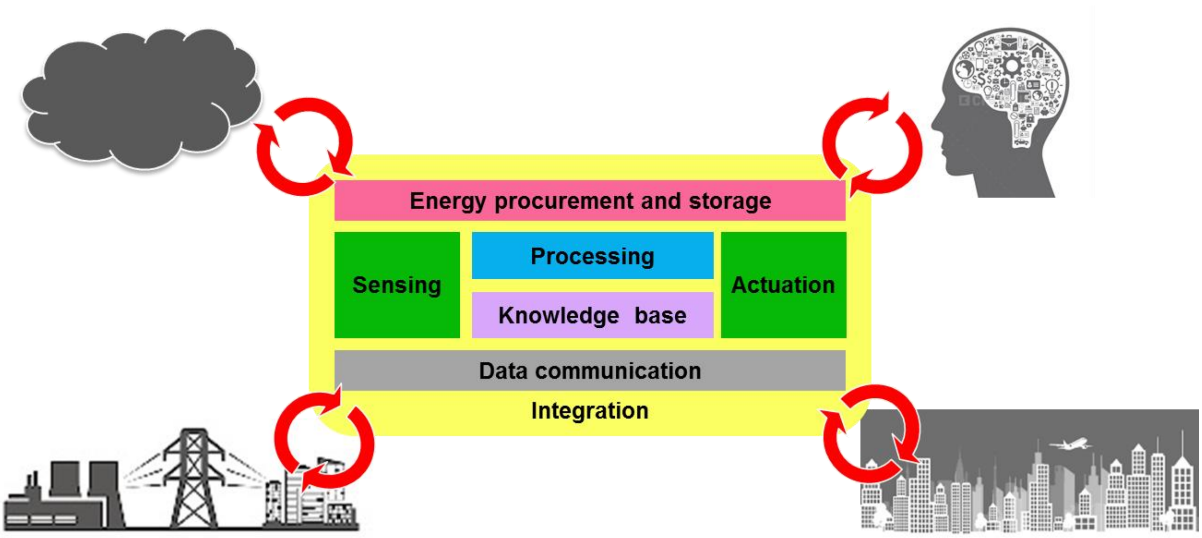


Figure 33: Structure of Smart Systems and their Interfacing to the Environment

R&D&I in Smart Systems Integration targets future improvements in the design, the functionality and the manufacturing of smart systems. These improvements are enabled by **heterogeneous (3D) integration** of new building blocks for sensing, data processing, actuating, networking, energy management and smart powering with batteries, external supplies or by energy harvesting and storage. Some examples of smart systems are shown in *Figure 34*.

Wireless sensor nodes for IoT (Bosch Connected Devices and Solutions)

Smart Hearables: personalised wireless hearing aid (Bragi, NXP)

Wireless Charging System for e-Mobility (Bosch)

Intraocular pressure measurement device (Sensimed, STM)

Recognition system for dangerous substances (FhG IPM)

Figure 34: Examples of Smart Systems

The building blocks of Smart Systems (proposed actions further detailed in *Figure 36*) combine nano-, micro-, and power-electronics with functions based on micro-electro-mechanical and other physical (e.g. electromagnetic, chemical and optical) as well as biological principles. They can be built out of a diversity of materials to ensure highest performance, reliability, functional safety and security as required for operation under complex and harsh conditions. They must be able to deal with multiple loads of critical magnitude and act simultaneously. SSI also addresses the integration of the systems into their target environment. This includes materials and technologies for the formation of surfaces and interfaces between the individual ECS in order to guarantee the required interconnect functionality in multiple ways, e.g. from rigid to flexible, from electrical or thermal connect to insulation, bio/chemically inert to activation layers etc. to achieve the desired form factors as well performance and robustness. Therefore, it is essential to include packaging as a functional part of heterogeneous (3D) integration and of the whole SSI, also to ensure reliability of the Smart Systems. SSI enables individual manufacturing as a key element in the factory of the future as well as predictive quality management by online monitoring of manufacturing processes. Smart systems will therefore be key elements of modern production lines. This includes the manufacturing processes of smart systems themselves.

Reliability during the operation phase of the product (defined as the ability to perform a defined function throughout the designed lifetime) can be improved by the smart system’s ability to continuously monitor its own health. This can be realized by for example, reporting key parameters to the cloud for online diagnosis, which results in prognostics, determining the remaining useful life and the system’s ability to re-configure to safe operation modes until maintenance or a replacement system is available.

Since SSI is usually based on the utilisation of new materials and technologies, and the products often are used in hostile environments, traditional standards used for assuring quality and reliability during design, manufacturing and testing/verification are often not relevant. Therefore, it will be essential to have a Physics-of-Failure approach for addressing the reliability of Smart Systems, both for experimental verification and by modelling. However, lack of relevant material data will also make it difficult to do adequate modelling.

9.2 Strategy

Funding instruments shall focus on the Smart System itself. Possible R&D&I activities cover necessary key components, their development and manufacturing, and the integration of Smart Systems into their environment, taking into account the requirements of a particular application or application domain. Therefore, building blocks of Smart Systems (sensors, actuators, controls and interfaces) need to be addressed, as well as technologies for safe, secure and efficient transfer of information and power and integration methods, enabling smart functionality, automation and **reliable operation** in harsh and complex environments. Smart System Integration is a crosscutting capability that requires, at same time, the investigation on new technologies (low TRLs) and the definition and study of their possible application (medium TRLs) before their complete exploitation in high TRLs. The following types of projects are envisaged:

1) Projects at lower TRL level
2) Large scale projects at higher TRL level
3) Pilot lines and projects which are able to provide the performance of the SSI solutions and support high TRLs for industrial usage.

It is recommended that a balance between low- and high TRL activities is sought.

9.3 Impact

The Smart Systems sector in Europe covers nearly all required technologies and competencies. With more than 6,000 innovative companies in the EU, the sector employs approx. 827,600 people (2012), of which 8% or 66,200 are involved in R&D with a budget of 9.6 B€ per year[43]. New R&D&I actions are expected to further strengthen the European leadership in Smart Systems technologies and to increase the global market share of European companies in the sector. New Smart System solutions will feature higher levels of integration, decreased size (x5) and decreased cost (x5). Time to market for subsequent products will be reduced by new designs, building blocks, testing and self-diagnosis strategies, methods and tools capable of meeting the prospect use-case requirements on reliability, robustness, functional safety and security in harsh and/or not trusted environments.

9.4 Cross references

The field of SSI draws upon key enabling technologies (KET) and integrates knowledge from a variety of disciplines. Furthermore, it bridges the gap between components and functional, complex systems. Within the framework of the ECSEL MASRIA, Smart Systems benefit from cross-links to all other essential capabilities. They are the key to novel functionality in all application areas. The development of Smart Systems will benefit from progress in nano-electronics, design methods and tool development. Smart Systems are key elements in a wide variety of activities, among others also in the Internet of Things and Services as well as for sensor-based electronic systems for Industry 4.0, Environment and Climate Action, Security, and Food and Water Supply:

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

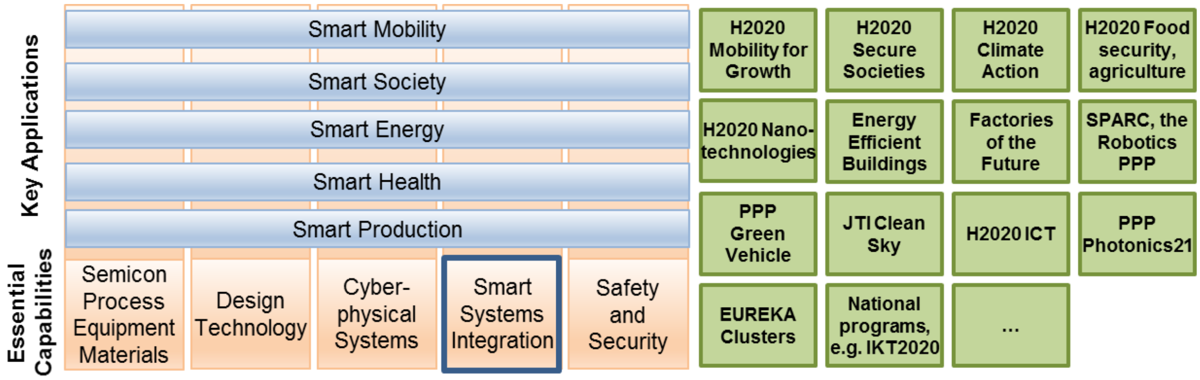


Figure 35: Smart Systems Integration cross links

9.5 Schedules/Roadmaps

Within the global trends of becoming a world where everything is connected, everything is smart, and everything is secure, Smart Systems Integration is at the core of the plethora of those smart devices. Smart Systems are the key enabler of the growing “Smartification” of applications. Together with the “Digitalization” process, both are allowing disruptive improvements in each aspect of human life. Smart Systems are becoming the ever growing intelligent interface to the physical world, providing new augmented experiences and the accessibility in every different domain, to functions, services and processes, becoming more and more complex and sophisticated. This revolution greatly affects our society: major impact on Consumer & Business sectors (Mobility, Production environments, Home & Building, Mobile and Wearable), growing impact on privacy, taking form in education & healthcare, with clear early effects for governments and policy shaping.

The achievements defined in the roadmaps shall support the short to long-term evolution of Smart Systems:

Short-term: Advanced 1st and 2nd generation Smart Systems, focussing on functional integration and networking of sensing and actuation combined with control, monitoring, communication and networking capabilities. In many cases these systems need to be self-sustaining and operate stand alone. Furthermore, integration of a secure solution, whether is software or hardware, is not a feature anymore, but a necessary requirement. Starting already on short-term, this approach will enable on long-term secure solutions in all domains of connected devices.

Mid-term: Strongly increased integration of sensors and actuators, management, energy-harvesting, transfer of energy supporting multifunctional perception, predictive, adaptive and advanced capabilities and self-test, network facilities, and suited for critical environments.

Long-term: Strongly improved technology and integration supporting 3rd generation Smart Systems with human-like perception, autonomy and decision processes, energy management, self-organizing networks, self-calibration and self-healing.

The evolution of Smart Systems can also be described in the **three-generation concept**, where the Smart Systems exhibit an ever growing intelligence:

1st Generation Smart Systems integrate sensing and/or actuation as well as signal processing to enable actions. Such Smart Systems are already routinely and successfully deployed in many sectors. Examples include: Systems that are able to monitor the health status of persons, the status of health and of functions of devices and to initiate necessary actions in a secure way, maintaining the privacy at the same time, e.g. pacemakers or safety systems in automotive applications such as airbag systems or electronic stability control systems for vehicles. Already in the 1st generation smart systems, the reliability and security by design should be addressed, ensuring secure solutions on the next generations.

2nd Generation Smart Systems are predictive and adaptive systems with self-testing capabilities, built on multifunctional perception and able to match critical environments. Moreover, they are equipped with network facilities and advanced energy harvesting and management capabilities. Systems of this generation are able to assess and address variability and uncertainty by generating an informed suggestion in the decision preparation process, which takes into account the original sample and the multitude of answers required by the detection objective. They will have the ability to learn and adapt, to change environmental conditions, and to respond accordingly. A striking example of a 2nd generation Smart System is a continuous glucose monitoring system for patients with diabetes, which is measuring subcutaneous fluid parameters, predicting blood sugar trends and warning the user to take action if needed. Cross-disciplinary development of 2nd generation Smart Systems may also enable simple artificial organs and in-body implants that work with the body chemistry rather than guarding themselves against it, as is the case with conventional heart pacemakers. Other examples of such systems that have already been introduced into the market include smart RFID labels with measurements of multiple parameters such as temperature, inclination and shock for transport monitoring, smart systems for cars, focusing on advanced hybrid and electric powertrain architectures and their connectivity and reliability.

3rd Generation Smart Systems exhibit human-like perception and autonomy and generate energy. The Smart Systems of this generation act independently and do not require any human control or decision. They may also be able to establish self-organizing communication networks and they develop from self-test to self-calibration, self-learning and self-healing. A prominent example of a 3rd generation Smart System is a highly or fully automated vehicle, which is executing steering, acceleration and deceleration autonomously. It does so by monitoring the propulsion system and driving environment by itself, and it either does not need the driver at all, or just as a backup. Other free-ranging systems, e.g. autonomous bio-robots and swarming agents interacting between the physical and virtual world, are at the far end of this vision. In order to become a commodity, the cost of third generation Smart Systems should be affordable for a large population all over the world.

The following tables/figures cover the roadmaps for the technology areas that are identified as essential for the further development of Smart Systems Integration. They detail the technical topics that should be a priority within the R&D&I actions. Where the Smart Systems itself together with all packaging, assembling, test and reliability aspect must be considered as specific topics and organized as European activities.

#	Topic \ Time (year of program call)	2017 - 2018	2019 - 2020	2021 - 2030
1. Building blocks of Smart Systems (sensors, actuators, controls and interfaces)				
SSI generation milestones	*M1.1: Short-term activities on smart systems*			
	M1.2: Mid-term activities on smart systems			
	M1.3: Long-term activities on smart systems			
1.1	MEMS and other physical, chemical and biological sensors and systems			
1.2	Effective and efficient mechanical, piezoelectric, electrostatic, electromagnetic, inductive, pneumatic, thermal, optical, chemical, biological and other actuators			
1.3	Modular and highly integrated schemes of power control and actuation			
1.4	Electrical, thermal, mechanical and biological energy management			
1.5	Energy generation and scavenging			
1.6	MOEMS, digital light, photonics and micro-optics			
1.7	Power electronic inverters/converters and high-density energy storage components			
1.8	Suitable and tailored structural, electronic, magnetic, piezoelectric, active, fluidic, biocompatible and other materials (for harsh environments)			
1.9	Wide band gap materials for power conversion as well as electro-active polymers and metal organic compounds			
1.10	Building blocks for advanced security functions, e.g. physical unclonable functions			

#	Topic \ Time (year of program call)	2017 - 2018	2019 - 2020	2021 - 2030
2. Safe, secure and efficient transfer of information and power				
2.1	Technologies for intelligent wired and wireless interconnection			
2.2	Body area networks			
2.3	Fast, compact, energy efficient, fail-safe and secure wireless communication systems for energy and data and technologies therefor			
2.4	Standardisation of machine to machine interfaces – both data and physical			
2.5	Strategies and technologies for the smart management of electric energy			
2.6	Technologies for energy generation, harvesting and storage			
2.7	Technologies for energy transfer such as wireless charging and seamless power supply			
2.8	Advanced solutions for thermal management			
2.9	Powerful computational and mathematical methods and algorithms for signal processing, data analysis, data fusion, data storage and data communication			
2.10	Hardware based data fusion methods and algorithms			
2.11	Dynamic, adaptive and cognitive data processing and methods for cognitive cooperation			
2.12	Dynamic integration of systems or nomadic devices in swarms			
2.13	Research on interfacing, networking and cooperation to enable distributed applications			
2.14	Technologies for mechanical, electrical, optical, chemical, and biological interfacing and transmitters and receivers for the transfer of energy and data			
2.15	Advanced intuitive man-machine interfaces and technologies therefor			
2.16	Secure data interfaces for the integration into the Internet of Things			
2.17	Safe and secure HW/SW platforms including privacy and security management			

#	Topic \ Time (year of program call)	2017 - 2018	2019 - 2020	2021 - 2030
3. Integration methods enabling smart functionality, automation and reliable operation in harsh and complex environments				
3.1	Multi-physics and multi-scale modelling and simulation methods for components, systems, data and communication channels			
3.2	Certification standards as well as design rules and testing and inspection methods			
3.3	Innovative manufacturing processes for top-down as well as bottom-up fabrication			
3.4	Methods and materials (metals, ceramics, polymers etc.) for system-level interconnection			
3.5	Methods for the physical system integration in-package, on-chip, on-surface, inside printed-circuits, on-tag, in-fabric, or on-PCB for systems			
3.6	Advanced (additive) manufacturing equipment and new integration methods on unusual substrates such as, for example, garments, construction materials or building structures			
3.7	Technologies for smart adaptation, self-testing, self-learning and self-healing at system level			

Legend:

planned in WP of ECSEL

market oriented Milestone from domain

derived milestone, when results at medium TRL needed

derived milestone, when results at low TRL needed

Figure 36: Roadmap of Implementation of Priority Topics in ECSEL Work Plans 2017-20

10 Safety and Security

Safety[44] (absence of catastrophic consequences on humans and the environment) as well as **Security** (the degree of resistance to or protection from harm) are both important criteria for dependability of a system. **Dependability** of a system is "the ability to avoid service failures that are more frequent and more severe than acceptable". Besides safety and security, dependability is measured against the following criteria: **Availability** - readiness for correct service; **Reliability** - continuity of correct service; **Maintainability** - ability to undergo modifications and repairs; and **Integrity** - absence of improper system alterations.

Safety and **security** as well as **dependability** engineering require the consistent merge of different engineering disciplines, leading to heterogeneous and possibly contradictory requirements. The goals of CPS (cyber-physical system) or I4.0 (Industry 4.0) designers typically – in particular in safety-critical environments - include 24/7 reliability, with 100% availability, and 100% connectivity, in addition to real-time response (time criticality, i.e. deadlines defined by the system integrators). However, other properties of dependability, such as safety and security, often end up in conflict with these goals. A safety-critical system might, for instance, shut down to avoid harm to its users, while a secure system might have to remove connectivity options that somebody could tamper with. A successful CPS or I4.0 facility is thus usually not optimal according to all the criteria of dependability, but achieves an acceptable compromise between them.

The engineering disciplines are coming both from **domains** (e.g., Systems- Software- and Hardware Engineering for electric/electronic systems, possibly taking into account further domains such as Mechanical-, or Thermo-dynamics Engineering in case of complex mechatronics systems such as automotive) and **methods** (e.g., Safety-, Security-, Reliability-, or even Dependability Engineering) point of view. Therefore, **two levels of challenges arise**: (a) the expertise in each single engineering domain, and (b) the consistent merging of the single aspects to a multi-sided product.

10.1 Objectives

Many systems in different industrial domains have obvious risks associated with failures. In safety-critical applications such as aircraft flight control or automated driving (SAE level 4 and 5), severe personal injury or equipment damage could result from errors and subsequent faults occurring in embedded computers. Furthermore, such applications also **need to be fail-operational**, since the effect shutting systems down is by itself catastrophic in many situations. Such systems require solutions like the employment of fail-operational, CPS, or distributed consensus protocols to ensure continued operation at any time and in any situation. However, many companies developing and manufacturing CPS causing personal or property damage cannot tolerate the added cost of redundancy in hardware or processing capacity needed for traditional fault tolerance techniques, like additional redundancy. Consequently, **low-cost, reliable, minimally redundant hardware** and **reliable software** are important design challenges for CPS and I4.0 facilities.

Furthermore, **rigorous qualification procedures** are necessary. Not only during first time development, but also after changes made to the design, in order to re-evaluate and assess the known failures, and to reduce the risk of system malfunction and subsequent failure.

[44] Particular focus is on functional safety while vehicle and road safety (European's Vision Zero) are covered by the smart mobility chapter.

Partitioning/synthesis strategies of CPS to **minimise recertification costs** poses another important challenge to be faced.

With the increasing mission importance of electronic systems and especially in the light of connected CPS systems the need for better methods and tools for verification and validation is emerging. Even for multiple connected systems the simulation of emergent behaviour cases should be possible and allow full functional safety analysis and prediction / avoidance of failure modes. For safety critical and security demanding applications these developments should lead to immediate support of certification actions, with incremental certification leading to significant savings in overall development process.

Security usually cannot be just added later on; it must be planned and designed during development process – **Security and Privacy by Design** are now known as engineering methods. However, security provision does not end with system deployment; it should be addressed like a process that needs to be maintained throughout the entire product lifetime. During development it is possible to test and assure product immunity against current threats, but in time new threats will appear and security can be impaired by new methods of attack. These aspects also include information privacy and personal data protection. Whenever I4.0 or IoT (Internet of Things) devices accommodate sensitive data, the loss, misuse, unwanted modification, or unauthorized access pose significant risks to individuals or businesses.

In the field of safety, methods for **quantified verification**, evaluation and assessment are already in place today. Current standards define metrics and target values depending on the risk level and criticality of the system under development. Despite the fact that security driven development processes are considered similar to safety driven ones, their quantified verification, evaluation and assessment is not that mature. Especially for more complex systems involving different suppliers and different domains, measurable security methods are desired.

Recent research has shown that safety and security development processes are considered similar to each other. This means that properties of safety and security may be analysed, specified, and verified in parallel using aligned methods. However, the interplay between both aspects depends on the target system and application. Since both development processes may be tailored according to the desired criticality, there is lots of room for optimization and efficiency.

A special issue in context of today's innovations is their **long-term security**. In the era of the internet-of-things (IoT) and with high availability of sophisticated hardware, the long-term security of today's CPS is completely unclear. New kinds of attacks emerge faster than ever before, featuring low entry barriers for everybody connected to the network. Typical examples include GPS spoofing attacks, jamming attacks or eavesdrop attacks. With increasing computational power security breaches in the field of CPS can be inevitable, as well as potentially severe in consequences and cost.

10.2 Strategy

Dependability and robustness are essential aspects for future CPS, I4.0 facilities and the IoT, especially when considering the growing degree of automation. Smart CPS environments incorporate a variety of sensing and actuation devices in a distributed architecture; such a deployment is used to create a digital representation of the evolving physical world and its processes for use by a broad range of applications. Mission critical tasks and applications must execute dependably despite disruptions caused by failures and limitations in sensing, communications, and computation.

Given the physical nature of these applications and the critical nature of some information, some issues may pose serious challenges, such as determining priorities perhaps through context-awareness and/or through criticality-based capabilities, and containment of the effect of propagated timing errors.

The following aspects are important bricks for a strategy towards safe and secure CPS, I4.0 facilities and IoT devices:

- **Systems engineering methods** to systematically reduce the development complexity and increase reliability and robustness by using appropriate software models and abstractions.
    - Embedded software architecture modelling
    - Software variability modelling
    - Software product line engineering
    - Model-driven software engineering processes
    - Reuse of architectural safety/security patterns
    - Secured development process (Automated code management, tests , security testing, vulnerabilities analysis, secure firmware & software updates)
    - Harmonized and interoperable security evaluation & certification
    - Security analysis and evaluation
    - Security & privacy by design
    - Safety and security patterns
    - Formal Methods for side fault analysis and fault attacks
    - Fault injections on Secure Element
    - White-Box Crypto: algorithms & attacks
    - Fully homomorphic Encryption: algorithms & attacks
    - Block chain, Post Quantum Cryptography, Quantum cryptography, Fingerprinting
    - Simulation environments for security evaluations of components and Systems
    - Artificial Intelligence for security fault prevention (adaptive security)
    - H/W-secured Smart Contracts
- **New design tools**
    - New security metrics
    - Safety and security co-design and co-analysis
    - Simulation techniques for safety and security analysis
    - Verification and validation of security requirements
    - Specification of secure systems and building blocks
- **Dynamic configuration**: as components appear and disappear as virtual devices, and communication links are established/released depending on the actual availability of network connectivity.
- **Self-diagnostic tools** and **robust control algorithms** that ensure adaptability and survivability in the presence of security attacks, random faults, unpredictable events, uncertain information, and so-called sensor false positives (sensor misinterpretations). Inclusion of models of the incentives of human decision makers in the design process to improve resilience.

- **Scalable Health Management Architectures**, integrating diagnostic and prognostic capabilities from single systems to systems of systems (from single board to complete aircraft) for reducing logistic impacts and Life Cycle Costs
- **Evaluation and experimentation** using extended simulation and test-bed infrastructures for an integration of Cyber-Physical Systems Platforms that directly interface with human decisions.
- **Architectures** which support distribution, modularity, and fault containment units in order to isolate faults.
  - New architectures integrating security to enable “security by design”
  - Re-use and integration of secure components and modular system certification
  - Secure hardware building blocks
  - Secure software libraries and components
- **Secure** real-time systems
  - Secure fault diagnosis and maintenance, e.g., remote downloading of control software remotely into the flash memory of a vehicle
  - Security of nomadic systems connected by wireless protocols
  - Security in dynamically reconfigurable real-time systems.
- Transparent **fault tolerance**
  - Advanced hardware-related and software-implemented fault-injection for dependability evaluation.
  - Provision of a generic fault-tolerance layer, independent of the application
  - Tolerance with respect to arbitrary failure modes of components
  - On-line maintenance of fault-tolerant systems
  - Automated reconfiguration
  - Low power
- **Certification** and component-based **recertification** of high-dependability applications
  - Modular certification of a composable design
  - Validation of high dependability
  - Proof of absence of failure modes with high impact (safety criticality)
  - Independent validation of component interface properties
  - Integration and validation of legacy systems
  - Worst-case execution time (WCET) research (hardware, algorithms, tools)
  - Standardised procedures and processes to develop and design dependable SoS
- **Identity and access management**
  - Identity management
  - User authentication
  - Multi form factor authentication
  - Peer authentication and context based security
  - Usability of authentication
  - Key generation and key management
- **Data protection**
  - Reliability and liability of data
  - Secured deployment
  - Security update in the field
  - Secured transmission
  - Secured physical layer in wireless systems
  - Secured distributions
  - E2E security (connected systems such as IoT and I4.0)
  - Interoperability and heterogeneity
  - Secure storage for keys and personal data
  - Protection against HW trojans

- **Safe & Secure execution platform**
    - Secure coding
    - Secure operating systems
    - Secure microcontrollers
    - Intrinsically secure IC's
    - Trusted Platform Module (TPM)
    - Trusted Execution Environment (TEE)
    - Embedded secure element
    - Secure boot process

- **Infrastructures**
    - Connected cars safety
    - Secured access to systems and infrastructure
    - Infrastructure protection against failure
    - Infrastructure surveillance and monitoring
    - Industrial asset management
    - Detection of abnormal behaviour
    - Safe and secure behaviour in case of failure
- **Authentication and anticounterfeiting**: Fake products are a significant threat to system manufacturers and original equipment manufacturers with regard to their investment. Authentication and anti-counterfeiting help deliver a premium user experience by checking that only authorized accessories such as earphones, flip covers and add on cameras are used, for example, with specific smartphones.
- **Trusted devices identities** are required as an authentication solutions for industrial automation systems, smart homes, consumer and medical devices as a critical success factor (e.g. trusted devices based on block chain)
- **Cryptography**
    - Fully homomorphic encryption: algorithms and attacks
    - Quantum cryptography and post quantum cryptography
- **Protocols**
    - Techniques to improve the efficiency in terms of cost, size and energy consumption of hardware and software solutions implementing currently well-known cryptography protocols and security infrastructures.
    - Mathematical analysis to design new scalable and efficient protocols, suitable for the new requirements of billions of connected smart devices
- **Packaging**
    - Improve the understanding of potential attack mechanisms and develop effective countermeasures to withstand these new attacks must be a key R&D&I point to allow further deployment of the fourth industrial revolution, especially in safety-critical systems
- **Chip architecture**
    - A generic processor coupled with a secured processor integrated as secure enclave in a single chip architecture or as a two chips solutions (SiP)
    - A generic processor plus additional memory protection unit(s) to insure a more protected processing and storage area within the circuit
    - A dedicated processor architecture integrating a trusted/secure set of operations (such as an ARM TrustZone, but potentially applied to lower end CPU)
    - Any further combination that could lead to appropriate safety/security levels
    - Multi-processor redundant architecture with integrity cross checking should be considered
    - All dedicated hardware resource access control

10.3 Impact

Cyber-Physical Systems are an integral part of our everyday lives and they are getting more connected and smarter. We are surrounded by smart mobility applications as connected vehicles, smart cities, smart grids, smart energy solutions, smart healthcare applications, and so on. These systems rely heavily on the safe and secure operation of embedded sensors and actuators despite limited computational capabilities and limited power/energy resources.

Dependable CPS are an enabler for increasing degree of digitalization in all industrial domains. This finally leads to increased competition in existing markets as well as open doors to new markets (e.g., data-driven business models). While CPS promises huge gains in resource efficiency, services individualization and greater adaptability, it presents new challenges a well, especially in terms of security. In an increasingly connected world, trusted systems are becoming a number one priority for many organizations. As the attack surface widens across both existing and emerging applications, the number and severity of potential threats are rising. The consequences of security breaches range from identity theft and fraud to operational downtime and business closure. Homeland security and public safety are further challenges of highest importance.

A success in overcoming the current challenges will lead to the development of systems and products (incl. services) which are needed to solve existing societal problems without increasing development costs. Scalable and efficient mechanisms to secure systems potentially consisting on billions of smart connected devices, with limited resources is the main challenge.

Cyber-Physical-Systems are only as safe and secure as the weakest element in the development and deployment chain. Deployment of CPS requires a strong R&D&I investment in order to develop solid mechanisms to protect against attacks, counterfeits, manipulation and sabotage in all manufacturing environments. Therefore, security aspects must be addressed from early development stages. Smart CPS infrastructure or I4.0 environments must be secured right from the manufacturing stage. Device manufacturers often have difficulties finding simple yet strong security solutions for establishment of robust trust mechanisms. This is often because of either constrained or limited resources, but also attributable to a lack of trust and control in the manufacturing environment. Security provisioning should take place towards the end of the production cycle, preferably during the quality assessment. Physical security of on-premise appliances will also need to be ensured by manufacturer. To compound the problem, information security is often a newer organizational competency for CPS manufacturers in context of their products, and these organizations are constantly evolving their understanding of protection against cyberattacks. Adding effective security technology to the embedded system allows the manufacturers to increase customer satisfaction and to protect their businesses. More importantly, safety and functionality can be protected throughout the life of the system.

On a larger scale, systems are evolving from single-owner designs to larger systems or even systems-of-systems, which communicate with each other, using internet or similar media, produced by multiple companies. Effective safety and security engineering methods and technologies will cope with this paradigm shift and will allow for larger market share, higher competitiveness of European industry in all application sectors addressed by the MASRIA and contributing to increase employment in Europe. CPS systems connect the entire value-added chain, from supplier and producer all the way to the customer. The success hinges on secure and smart systems and components.

10.4 Cross references

Safety and security are required for all applications addressed in this MASRIA, described under “Smart everywhere”. They are also essential in the design of *Cyber Physical Systems* and *Smart Systems Integration*; hence, a strong interaction with these two technology areas is expected. In order to finally succeed on the implementation of safe and secure overall systems, all product relevant domains need to be considered.

For example, the automotive functional safety standard ISO 26262 defines a top-down development process, taking all levels of the automotive supply chain into account. Each level cross-refers to other domains, e.g. safety analyses must be carried out with respect to understanding of other involved domains.

10.5 Schedules/Roadmaps

The following table gives a list of relevant topics and fields and how these might develop until 2020+.

Topic	2017	2018-2019	2020 & after
Safety. security & privacy by design	Requirement specification for safety, security, privacy and trust	Advanced tools and methods to support security schemes and safety patterns for focused problem areas	Fully integrated safety and security requirements & generic components and frameworks
Authentication	Authentication scenarios to access various services (internet or cloud services), support multiple authentication schemes for users	Multiple authentication options are available for all authentication scenarios	In all authentication scenarios, where legally allowed, users can choose the attributes they would like to use for authentication within limits (e.g. consumer protection).
Distributed models of trust	System architecture to define, compute, and deploy trust in complex domains including credential provisioning	Integration of secure architectures, including roots of trust within systems for the various application segments	Unified computational trust models are able to support several scenarios
Decentralized trust frameworks (blockchain)	Improve theoretical model and study feasibility	Deployment of decentralized trust models to several application domains	Generalization of decentralized trust framework
Data Protection	Definition of new models reflecting data confidentiality needs & integrity/availability constraints	Efficient techniques for enforcement of secure data storage and management, integrity & availability opposed to identified constraints	Continuous monitoring and certification of data confidentiality & integrity
Network Protection	Security of existing technologies and standards (SDN, NFV, 5G)	Virtual isolated networks with guaranteed security properties	Privacy and security by design, virtual networks for all applications and services
Safety and security risks related to infrastructures (systems of systems, cloud, new generation networks)	Identify potential new risks at higher levels of abstraction	Propose security solutions for new cyber risks, as well as advanced safety solutions for systems of systems and infrastructures	Standardized model for implementing the most effective solutions
Safe and secure execution platforms	Protection and sharing mechanisms for existing virtualization solutions	New approaches for safe and secure HS/SW virtualization	Development of trustworthy and reliable platforms, mobile & cloud solutions

Safe and secure updates in the field	Development of new mechanism for updating systems in the field	Implement new prototypes of “updatable systems” while maintaining availability and security	Roll out new “updatable systems”, replace existing systems
Safety and security aware development	Safety and security metrics for development and operations	Safe and secure software development for continuous delivery models: controls, testing, patching	Integrated standards, concepts and tools, covering application security, safety and security management including certification
Safe and secure services	Identification of threats, criteria, and metrics for evaluation of systems and services regarding safety and security	Automated tool and/or guideline supported evaluation process, audits, certifications and managed operations	Advanced strategies, heuristics, and intelligent solutions for evaluation of audits, certifications and managed operations

Figure 37: Safety and Security roadmap

Part C: Relevant Annexes

11. Annexes

11.1 Annex to A1: Smart Mobility

No annex text for Smart Mobility.

11.2 Annex to A2: Smart Society

Securing critical community assets

Secure and safe management and trusted processing of the entire system for European-wide applications, both at the infrastructure and at the devices level, is one of the major challenges in a smart society. Privacy must be protected at all times. First set of mandatory items to be addressed are:

1) Trusted execution, computing and connectivity for embedded systems and complex information networks and computing systems
2) Validation, verification and proof of safe and secure infrastructure and services (trust provided to end users and customers - for example, OEMs, cities, etc.)

Trusted components and systems

Many applications in the scope of smart societies are characterized by data transfer over wired / wireless network connections. If no preventive actions are taken the applications are vulnerable to intruders who could try to steal or modify data. Attacks on payment transactions, attacks on critical infrastructures and theft of digital identity are very well known examples. To protect the integrity of the data and to guarantee the identity through strong authentication plus privacy protection of the transmitters, security is required on all levels of the implementation. However, to establish “security by design” the protection has to be an intrinsic part of the overall product architecture of the application itself. Beside that a secured and managed deployment has to be considered. Only then the so-called end-to-end security of a connection can be established. The level of security will depend on the sensitivity of the data. To that end, we propose the following topics to be addressed:

1) Next-generation hardware building blocks with improved security and safety (e.g. by larger embedded non-volatile memories for embedded software stacks)
2) New form factors integrating secure and safe elements; related trust and security hardware and firmware features for embedded computing platforms.
3) Security based on design time and tested cryptography
4) Protection and unique generation of secret keys by physical unclonable functions (PUF) against tampering and fraud
5) Technologies that enable isolation of attacked parts of systems in order to keep the minimum functionality available even in case of an attack (e.g. protect against shut down of systems, DDoS, blackouts, etc.)
6) Technologies for decentralized security, where security breaches can be detected early and breaches never compromise all the components
7) Secure M2M communication technology as the foundation for the internet of things that can be trusted and is self-organizing
8) Fast and low energy communication protocols for the next generation of IT architecture (smart manufacturing) that enable self-adopting and self-controlling functionality

9) Improved trusted virtualization and compartmentalized operating systems; multi- level security according to targeted protection profile(s)
10) Platforms to ensure a Safe and secure deployment including the remote monitoring and management within new applications related to the Internet of Things such as smart grids, smart cities and building, smart mobility, manufacturing, e-health etc. (with heterogeneous systems for smart mobility, smart objects for e-Transaction and embedded machine-to-machine communication), integration with enterprise IT security

Next generation digital lifestyle

Impact: Breeding global champions and strong local clusters

Digitalization changes the industry dynamics, especially in terms of scalability of businesses (= positive marginal return with respect to resources). New hyper-scalable businesses, based on digital services and digital products, have emerged, where the marginal return increases according to the Metcalfe's law. Initial examples are from gaming and entertainment, but with Internet of Things making the real world susceptible to digital tools and ways, the new industry dynamics will eventually find its way to the realm of traditional businesses and the whole society. The winner is the one who gets most users and takes it all in terms of profit. Therefore it is necessary to have a fair share of European winners and strong local clusters to help them initially succeed and monetize the success in local jobs and economic growth.

The Internet has evolved over the last decades into a mature network technology providing ubiquitous connectivity that in general can manage the volume of data required by the current broadband services; the next generations of the Internet will evolve beyond this and provide more services and functionality enabled by the always connected necessity brought by the social network users.

The consumer will have access to multiple multimedia services through a variety of devices connected to ubiquitous networks with improved intuitiveness in interaction in order to enhance user experiences; and to enable broadcasters and content providers to produce multi-platform content and seamlessly deliver it in a plurality of new formats at reduced cost. User authentication to services is non-intrusive, seamless and secure through different authentication techniques. The increasing amount of different sorts of data will lead to an increasing role of data management. Future networks will provide high-capacity at low cost and low energy consumption. The reduction of latencies as well as the increase of bandwidth will enable enhanced real-time interaction and more cloud based applications such as:

1) Tactile internet (e.g. remote surgery, interactive e-shopping).
2) Video on demand (e.g. TV over internet (IPTV), Over The Top content (OTT)).
3) Improved video surveillance and conferencing (everywhere for everybody), for private and security applications.
4) Secure and convenient Contactless payment and ticketing.
5) Traceability (food processing, forest products, logistics, etc.).
6) Convergence of app services with physical world: e.g. direct download of access right to one media (smartphone or tablet): e.g. hotel room key, visitor’s badge, visa, legitimations, etc.
7) Secure Home automation (smart lighting, heating and ventilation, automatic tariff selection, smart energy, etc.).
8) Online Gaming with very low latency.
9) More energy efficient networks both in computing, e.g. by using photonics at the heart of the high-speed broadband services as well as in network operation.

10) Voice over LTE improving audio user experience.
11) Augmented and virtual reality applications.
12) Towards the ‘unpad’ era, “the naked approach”, with gesture haptics and voice control as alternative HMI approach.

The ubiquity of mobile devices and the wireless networks deployments offer extensive need for energy efficient, robust and secure wireless interfaces at device level. Short-range connectivity seems to be an interesting development path. In the long term the goal is to develop low cost single-chip sensor node systems to sense, communicate, reason and actuate. Such a sensor node will:

1) Enable the Internet of Things (IoT)
2) Provide capabilities for machine-to-machine (M2M) communication
3) Make smart devices ubiquitous and
4) Pervade people’s environment (for example in smart cities, smart buildings, …) with computing power and functionality boosted by technologies such as Near Field Communication (NFC), Radio Frequency Identification (RFID), Bluetooth Low Energy, etc.

See also chapter 2 “Communication and Digital Lifestyle” of the AENEAS Agenda.

11.3 Annex to A3: Smart Energy

No annex text for Smart Energy.

11.4 Annex to A4: Smart Health

No annex text for Smart Health.

11.5 Annex to A5: Smart Production

No annex text for Smart Production.

11.6 Annex to B6: Semiconductor Manufacturing and Technology

Grand Challenge (PTI) 1: Semiconductor process technology and integration for advanced and distributed compute infrastructure and system performance scaling

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

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

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

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

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

Grand Challenge (PTI) 2: Semiconductor process technology and integration of devices and components at chip-level and SoC for the complex heterogeneous functionality

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

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

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

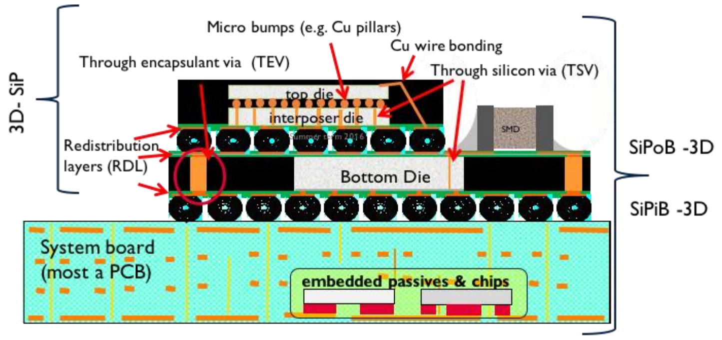
Analog functionality will be introduced in systems through e.g. (i) integrated application-defined sensors technologies. With the recent success of on the fields of mmWave sensors and MEMS devices enabled by high volume semiconductor manufacturing capabilities in automotive and consumer applications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

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

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

Grand Challenge (PTI) 3: Process technology and integration for advanced smart System-in-Package applications

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



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

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

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

At the macro-scale level, a system can be seen as consisting of a collection of large functional blocks ('tiles', IP blocks). These functional blocks have quite different performance requirements (analog, high voltage, embedded non-volatile memory, advanced CMOS, fast SRAM,...) and technology roadmaps. Therefore it is of increasing interest to split the system in heterogeneous parts, each to be realized by optimum technologies at lower cost per function, and recombining the system using a high-density 3D interconnect processes. It is clear that 3D integration in electronic systems can be realized at different levels of the interconnect hierarchy, each with different vertical interconnect density. Different technologies are therefore required at different levels of this 3D hierarchy.

Research and development priorities are on:

- innovative interconnect technologies, that allow vertical as well as horizontal integration. This includes process technologies for vertical interconnects like Through Silicon Via (TSV), Through Encapsulant Via (TEV) technologies, and micro-bumps, as well as process technologies for horizontal interconnects like thin film technologies for redistribution both on chips and on encapsulation materials. We must provide the technology base for 3D stacking as well as horizontal interconnecting of dies, the latter might be needed because of heat dissipation.

- encapsulation technologies, handling carriers as well as panels which on the one hand protect the dies, but on the other hand allow optimum electrical performance. Chip embedding technologies like chip embedding in mold material (e.g. fan-out WLP or eWLB technologies) and chip embedding in laminate material, for both Europe already has a strong capability, must be sustainably supported to prepare the next generation.
- process technologies for integration of additional functionality like antennas or passive devices into a system-in-package. This additional functionality will be door-opener for new applications.
- high integration density and performance driven 3D integration (power/speed). For this category denser 3D integration technologies are required: from the chip I/O-pad level 3D-SIC to finer grain partitioning of the 3D-SOC and the ultimate transistor-level 3D-IC (See Strategic thrusts 10 for the 3D landscape).
- reliability and quality. For this a close consideration of the chip/package interaction, but also of the interaction of chip/package to the board is required. All the research and development needs a strong link especially to materials research and compatibility. In the last 10 years nearly all assembly and packaging materials changed and in the next 10 years it is expected they change again. Also a close link to the design chapter is crucial. Chip-Package-Board co-design will be of outstanding importance for introducing innovative products efficiently with short time to market.
- system integration partitioning: The choice of the 3D interconnect level(s) has a significant impact on the system design and the required 3D technology, resulting in a strong interaction need between system design and technology.

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

Grand Challenge (EMM) 1: Develop European know-how for advanced Equipment, Materials & Processes for sub-10nm semiconductor devices & systems manufacturing

This Grand Challenge targets the development of new equipment and material solutions for sub-10nm semiconductor technologies that enable high volume manufacturing and fast prototyping of electronic devices in CMOS and beyond CMOS technologies, and therefore will allow to supply the world market with technology leading, competitive products. The overarching goal of the equipment and material development is to lead the world in miniaturization techniques by providing appropriate products two years ahead of the shrink roadmap of world’s leading semiconductor device and components manufacturers. Internationally agreed roadmaps such as the ITRS (International Technology Roadmap for Semiconductors) and its successors will also be taken into consideration.

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

1) Advanced lithography equipment for sub-10nm wafer processing using VUV and EUV, and corresponding sub-systems and infrastructure, and mask manufacturing equipment for sub-10nm mask patterning, defect inspection and repair, metrology and cleaning.
2) Advanced holistic lithography using VUV, EUV and NGL techniques such as e-beam and mask-less lithography, DSA and Nano-Imprint.

3) Multi-dimensional metrology (MDM) and inspection for sub-10nm devices which combines holistic, hybrid, standalone setups (of Optical, fast AFM, E-Beam, scatterometry, X-Ray and STEM technologies) for mapping the device material and dimensional properties and defectivity, with productivity aware design (PAD) techniques such as: recipe automation, fleet management, 'close-to-process' monitoring and big data support with predictive methodologies.
4) Thin film processes including thin film deposition, such as (PE)ALD and PIII for doping and material modification, and corresponding equipment and materials.
5) Equipment and materials for wet processing, wet and dry etching, thermal treatment, and wafer preparation.
6) Si-substrates, Silicon on Insulator substrates, SiC, III-V materials, advanced substrates with multifunctional layer stacking, including insulators, high resistivity bulk substrates, mobility boosters, corresponding materials, manufacturing equipment and facilities.

Expected Achievements/Innovation Foreseen:

Ambition of the European E&M industry for advanced semiconductor technologies is to lead the world in scaling by supplying new equipment and new materials approximately two years ahead of the volume production introduction schedules of advanced semiconductor manufacturers. Main focus will be on equipment and materials for lithography, metrology and deposition including the respective infrastructure for sub-10nm technologies.

Grand Challenge (EMM) 2: Strengthen European competitiveness by developing advanced More-than-Moore (MtM) Equipment, Material and Manufacturing solutions for front-end-of-line (FEOL) and back-end-of-line (BEOL) wafer processing and device assembly and Packaging (A&P)

More-than-Moore (MtM) technologies will create new technological and business opportunities and demand new skills and know-how in areas such as 3D heterogeneous integration and advanced system-on-chip (SoC) solutions. The overall goal for European E&M companies is to enable semiconductor manufacturing companies to produce sensors including MEMS (Micro-Electro-Mechanical Systems), Advanced Imagers, power electronics devices, automotive electronics, mm-wave technologies, and advanced low-power RF technology.

For MtM, which is a definite European strength, 200 mm as well as 300 mm technologies will be the main focus. For system integration equipment capable for combining chips from both wafer technologies is required.

In the coming years, 3D integration and SoC manufacturing will add complexity to the global supply chain and generalize the concept of distributed manufacturing. This will require the development of new concepts for Information and Control Systems (see Grand Challenge 3). The interfaces and handovers between wafer technologies and A & P need to be clearly defined and require innovative equipment.

MtM technologies will require working more closely together, combining front-end wafer equipment and assembly and packaging (A&P) equipment. Technologies and methodologies well established for Si wafers will partially be reused and adapted for A&P.

New materials and new equipment will be required for future A&P, creating new R&D challenges and new business opportunities. Over the last decade, nearly all assembly and packaging materials have been replaced by more advanced materials - a process that is ongoing. This will have a strong impact on future processes and equipment.

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

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

Expected Achievements/Innovation Foreseen:

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

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

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

Furthermore, the trend in MtM solutions of ever decreasing feature size, with ever-increasing number of features, and interconnects packed onto an IC, puts strong demands on product validation and verification methodologies and on test methodologies and equipment.

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

Grand Challenge (EMM) 3: Develop new fab manufacturing and appropriate E&M solutions that support flexible, agile and competitive semiconductor manufacturing in Europe and supply the worldwide market with correspondingly 'best-in-class' hardware and software products

The Grand Challenge 'Manufacturing' focuses on research and development in E&M to enable highly flexible, cost-competitive, 'green' manufacturing of semiconductor products within the European environment. The overarching goal is to develop new wafer fab management solutions that support flexible and competitive semiconductor manufacturing in Europe, as well as supplying the world market.

For that, aspects of Industry4.0 need to be incorporated, with focus on resilient and sustainable manufacturing, and the move from "APC-enabled" equipment to cyber-physical systems. The developed solutions should include innovations for resource saving, energy-efficiency improvement and sustainability, without loss of productivity, cycle time, quality or yield performance, and for reduced production costs. A key will be to invest in people's skills and competency to adapt work-flows to new, data-driven manufacturing principles.

Solutions for manufacturing will have to address related challenges, respecting Industry4.0 principles, and are similar for both manufacturing domains: Innovative solutions are required to control the variability and reproducibility of leading-edge processes. This implies that domains traditionally seen as disconnected (for example, Statistical Process Control (SPC), Fault Detection and Classification (FDC), process compensation and regulation, equipment maintenance and WIP (Work in Progress) management will have to become tightly interconnected. Moreover, blurring of the frontiers between these domains will require considerable consolidation of knowledge capitalization and exchange of knowledge. Factory Integration and Control Systems will have to become modular, allowing information to flow between factories in order to facilitate rapid diagnostics and decision making, also through BYOD (Bring Your Own Device) concepts. The focus of high-mix/low-volume manufacturing will be on flexible line management for high mix, and possibly distributed manufacturing lines. New manufacturing techniques combining chip and packaging technologies (e.g. chip embedding) will also require new manufacturing logistics and technologies (e.g. panel molding etc.).

To achieve this, new fab management and equipment solutions will be required in several fields. An overview is given in appendix A3.

Expected Achievements/Innovation Foreseen:

Future innovations should address new automation techniques and automation software solutions as well as innovative man-machine solutions. Furthermore, also new environmental solutions (e.g. in terms of energy consumption, chemical usage) and in this regard new materials (for example, in terms of quality, defectivity, functionality) will be needed.

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

For example, a successful outcome would be the creation of high-performance computing systems for process control that are useful for multiple European companies. Accordingly, focus topics should include, among others, factory operation methodologies, data acquisition and analysis concepts, factory information and control systems, materials transport as well as local storage and fully automated equipment loading/unloading.

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

11.7 Annex to B7: Design Technology

No annex text for Design Technology.

11.8 Annex to B8: Cyber-Physical Systems

No annex text for Cyber-Physical Systems.

11.9 Annex to B9: Smart Systems Integration

No annex text for Smart Systems Integration.

11.10 Annex to B10: Safety and Security

No annex text for Safety and Security.

12 Table of Figures

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