Multi-Annual Strategic Plan ("MASP") 2018

REVISION STATUS		
0	First Draft, based on ECS industry SRA draft	2017-11-08
1	First version, from official MASRIA V2	2017-11-14
2	Auto cross-referencing corrected. "Contributors" chapter removed (is in SRA/MASRIA)	2017-11-17
3	Clarification of CSA as an instrument. Update Matrix diagram to be consistent with that used by the Associations. "DRAFT" watermark added	2017-11-20

Contents

1 Introduction 8
1.1 Vision, mission and strategy 9
1.2 Objectives 13
1.3 Relationship with other programmes 17
2. Roadmap 18
2.1. High-level goals 18
2.2. Focus Areas 19
3. Making it happen 21
3.1. Research and Innovation Actions (RIA) 22
3.2. Innovation Actions (IA) 22
3.3. Lighthouses 23
3.4. Multi-funding actions 24
3.5. Excellence and competence centres 24
3.6. Innovation support actions 25
4. Financial perspectives 26
5. Project selection and monitoring 27
6. Transport & Smart Mobility 29
6.1. Executive Summary 29
6.2. Relevance 29
6.3. Major Challenges 31
6.4. Make it happen 42
6.5. Timeframes 43
6.6. Synergies with other themes 44
7. Health and Well-Being 45
7.1. Executive summary 45
7.2. Relevance 46
7.3. Major challenges 49
7.4. Timeframes 61
8. Energy 62
8.1. Executive Summary 62
8.2. Relevance 62
8.3. Major Challenges 66

8.4. Make it happen 74
8.5. Timeframes 75
8.6. Synergies with other themes 76
9. Digital Industry 77
9.1. Executive Summary 77
9.2. Relevance 77
9.3. Major Challenges 80
9.4. Make it happen 90
9.5. Timeframes 91
9.6. Synergies with other themes 92
10. Digital Life 93
10.1. Executive Summary 93
10.2. Introduction 93
10.3. Major Challenges 100
10.4. Timeframes 106
10.5. Synergies 107
11. Systems and Components: Architecture, Design and Integration 108
11.1. Executive Summary 108
11.2. Relevance 109
11.3. Major Challenges 113
11.4. Expected achievements 123
11.5. Make it happen 124
11.6. Timeframes 125
11.7. Synergies with other themes 131
12. Connectivity and Interoperability 134
12.1. Relevance 134
12.2. Major Challenges 138
12.3. Make it happen 142
12.4. Timeframes 143
12.5. Synergies with other themes 143
13. Safety, Security and Reliability 144
13.1. Executive Summary 144
13.2. Relevance 144
13.3. Introduction to Major Challenges 146

13.4. Timeframes 159
13.5. Synergies with other themes 163
14. Computing and Storage 164
14.1. Executive Summary 164
14.2. Relevance 164
14.3. Major Challenges 166
14.4. Make it happen 186
14.5. Timeframes 188
15. Electronics Components & Systems Process Technology, Equipment, Materials and Manufacturing 189
15.1. Executive summary 189
15.2. Impact 189
15.3. Major Challenges 190
15.4. Strategy 201
15.5. Timeframes 202
15.6. Cross references & synergies 204
16. Appendix to Chapter 6 207
16.1. Competitive situation of automotive industry in Europe 207
16.2. Details to high priority R&D&I topics for Grand Challenge 2 in Application Chapter Transport & Smart Mobility 208
17. Appendix to Chapter 10 212
17.1. Major Challenge 1: Managing critical, autonomous, cooperating, evolvable systems 212
17.2. Major Challenge 2: Managing Complexity 213
17.3. Major Challenge 3: Managing Diversity 215
17.4. Major Challenge 4: Managing Multiple Constraints 216
17.5. Major Challenge 5: Integrating miniaturized features of various technologies and materials into smart components 217
17.6. Major Challenge 6: Providing effective module integration for highly demanding environments 218
17.7. Major Challenge 7: Increasing compactness and capabilities by functional and physical systems integration 219
18. Appendix to Chapter 13.4.4 221
19. Further reading 222
19.1. Further reading for chapter 8 222
19.2. Further reading for chapter 9 222

20. References 223
20.1. References for chapter 5 223
20.2. References for chapter 12 224
21. Acronyms used in the document 226

1 Introduction

This 2018 Multi-Annual Strategic Plan (MASP) of the ECSEL Joint Undertaking reflects the Multi Annual Strategic Research and Innovation Agenda (MASRIA), prepared on behalf of the ECSEL JU by its Private Members Board (PMB). This MASP describes* the Vision, Mission and Strategy shared by the Members of the ECSEL JU, as well as describing 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 allow the ECSEL JU to fulfil its objectives.

Compared to the earlier MASPs, the set-up of this MASP 2018 is significantly renewed according to the decision of the PMB to issue a MASRIA with a strong link with a new initiative of the Private Members: a common pan-European SRA on Electronic Components and Systems[2]. This ECS SRA, that is funding-programme-agnostic, will be issued in a final draft form in November of 2017 and will be issued in its final form during the first quarter of 2018.

Further, this MASP will, where possible, refer to and reflect the outcome of the Interim Evaluation of the ECSEL Joint Undertaking (2014-2016) Operation under Horizon 2020[3].

The MASP identifies and explores specific Electronic Components and Systems (ECS) technology solutions for Electronic Components and Systems' (ECS) applications that are relevant enablers for addressing societal challenges and supporting 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).

[2] Electronic Components and Systems Strategic Research Agenda (ECS SRA 2018) to be published in the 1st quarter of 2018. This MASRIA 2018 is related to the final draft V4 of the ECS SRA 2018.

[3] http://ec.europa.eu/research/evaluations/pdf/ecsel.pdf

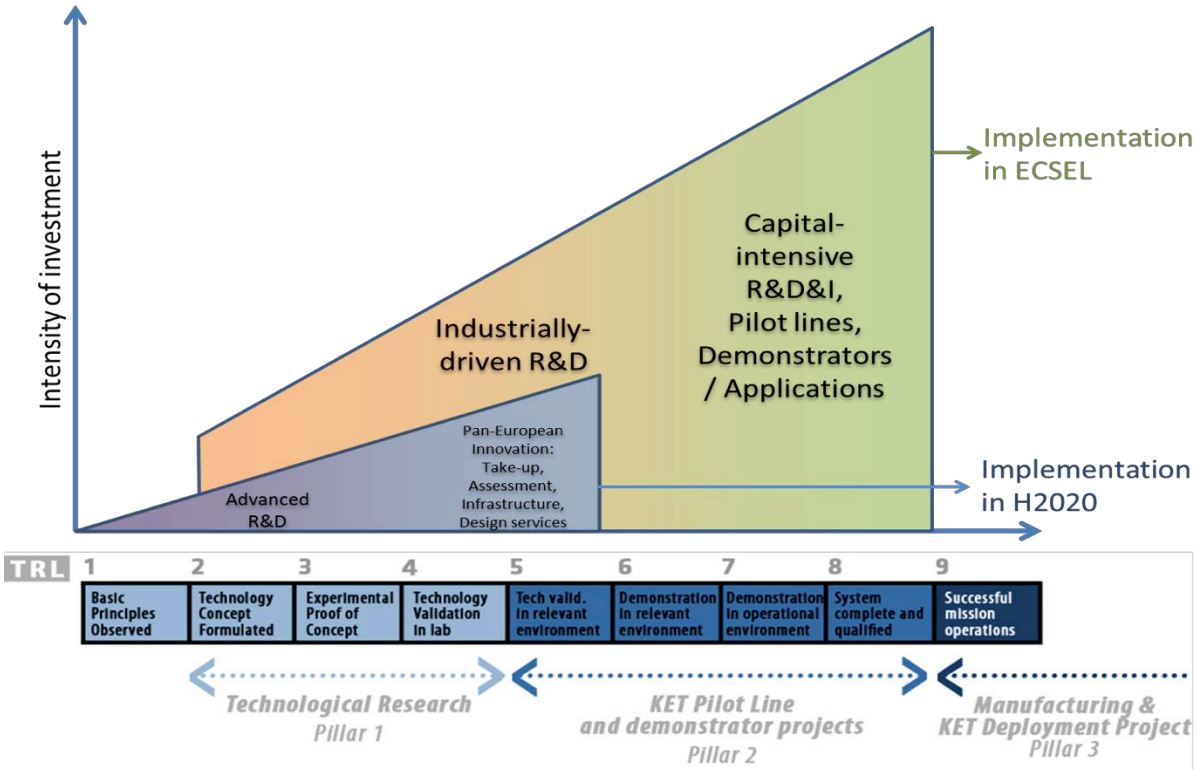


Figure 1 - ECSEL JU and H2020 actions

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.[4]

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 ECS technology basis for the above and as cornerstone for the realisation of a smart, sustainable and inclusive European 2020 digital society.

Digital technologies are an essential part of the answers to many of the daunting challenges that we are facing today: mounting insecurity, ageing population, air quality degradation in large cities, traffic congestion, unemployment, to name a few. They will impact the everyday life of citizens as

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

well as all business sectors. This Digital Transformation of Europe represents a great opportunity for the deployment and take-up of digital technologies. On one hand, digital transformation opens new opportunities for giving access and facilitating the use of new technologies and, on the other, it is widening the scope for every business in European and worldwide new markets where innovative digital products and services are expected: The future of Europe is Digital.

McKinsey estimates that digitalisation will potentially add 1 trillion EUR to the GDP in Europe as our daily lives and economies become increasingly dependent on digital technologies.

At the core of everything digital are Electronic Components and Systems (ECS), where the components are the basic parts of the systems, and 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. Components can be hardware-components, or software-components. A “system” designed and implemented within a given development process may be integrated as a “component” into a higher-level “system” within another development process. These Systems typically include hardware and software parts.

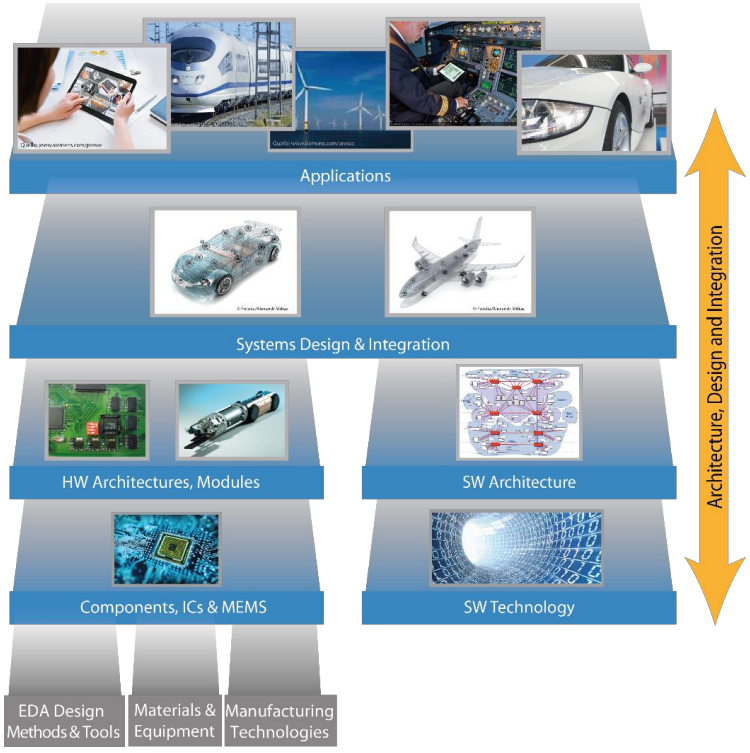


Figure 2 - Electronics Value-Chain

Innovation, along with rapid developments across technology, media and telecommunications, is creating the foundation to transform the way we work and live. The falling cost of computing power and data storage, the rise of broadband, ubiquitous connectivity and mobility have combined to create the dawn of a digital area filled with ever fast evolving technologies, as well as radically and fast changing business models and lifestyles. The emerging ecosystems around embedded intelligence and artificial intelligence technologies, blockchain and security, the Internet of Things

(IoT)5, High Performance Computing, the ever-growing miniaturization, among others, have quickly moved from cutting-edge to being on the verge of mainstream thus creating new paradigms.
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.

In Art. 2.1 of the ECSEL Council Regulation, 8 objectives are mentioned as targets for this mission:

The ECSEL Joint Undertaking shall have the following objectives:

- *(a) to contribute to the implementation of Regulation (EU) No 1291/2013, and in particular part II of Decision 2013/743/EU;*
- *(b) to contribute to the development of a strong and globally competitive electronics components and systems industry in the Union;*
- *(c) to ensure the availability of electronic components and systems for key markets and for addressing societal challenges, aiming at keeping Europe at the forefront of technology development, bridging the gap between research and exploitation, strengthening innovation capabilities and creating economic and employment growth in the Union;*
- *(d) to align strategies with Member States to attract private investment and contribute to the effectiveness of public support by avoiding an unnecessary duplication and fragmentation of efforts and by facilitating the participation of actors involved in research and innovation;*
- *(e) to maintain and grow semiconductor and smart system manufacturing capability in Europe, including leadership in manufacturing equipment and materials processing;*
- *(f) to secure and strengthen a commanding position in design and systems engineering including embedded technologies;*
- *(g) to provide access of all stakeholders to a world-class infrastructure for the design and manufacture of electronic components and embedded/cyber-physical and smart systems; and*
- *(h) to 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.*

To achieve the mission and its objectives, specifically when defined as “ensure”, “secure”, “maintain” and “grow” a lot of parameters (as for instance level playing fields; see [4]) play a role of which many are

[5] IoT: McKinsey & Company Global Institute in its report: Internet of Things: Mapping the value beyond the hype – June 2015 define IoT as: sensors and actuators connected by networks to computing systems. These systems can monitor or manage the health and actions of connected objects and machines. Connected sensors can also monitor the natural world, people and animals. They exclude systems in which all of the sensors primary purpose is to receive intentional human input, such as smartphone apps where data input comes primarily through a touchscreen, or other networked computer software where the sensors consist of the standard keyboard and mouse.

outside the scope and influence of ECSEL and other transnational R&D&I cooperation programmes. As far the transnational cooperation R&D&I programmes do play a role the following strategy (including many strategy-elements) will be followed.

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 to sustain positions 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 innovation to guarantee strategic independence in the face of increased globalisation.

Opportunities for large projects, exploiting Europe's 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 strengthen 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 [6] of which over 1 million direct and induced jobs in the semiconductor industry[7]. Together, they allow Europe to address a global market of more than 2,600 billion $ (see [6]) enabling the generation of at least 10% of GDP in the world (see [7]).

[6] ITEA/ARTEMIS-IA High-Level Vision 2030, version 2013.

[7] A European Industrial Strategic Roadmap for Micro- and Nano-Electronic Components and Systems (Jan. 2014).

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 combining 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.

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 [7]). Furthermore ECSEL is an important instrument to help realise the strategies as formulated by the High Level SRIA, the ITEA/ARTEMIS-IA High Level Vision 2030 (see [6]), the AENEAS Strategic Agenda and the SRAs of the ARTEMIS-ETP, EPoSS-ETP and certainly the new ECS SRA by AENEAS, ARTEMIS-IA and EPoSS.
2) The ECSEL actions will focus on European industrial strengths and opportunities for the European ECS value chain. Its innovation actions will continuously boost competitiveness of the European ECS industry in a balanced way. ECSEL focus is on the full ECS value chain.
3) Lighthouse initiatives: The goal of Lighthouse Initiatives is to focus part of the ECSEL JU activities on achieving concrete socio-economic objectives along an agreed approach, including for establishing de facto standards when appropriate. Lighthouse Initiatives should improve and accelerate the impact of relevant projects by engaging all needed actors in the supply/value chain to achieve these goals and by connecting investment in R&I in ECSEL JU to investments done, for example, in application areas in the Societal Challenges in HORIZON 2020 or EUREKA as well as giving recommandations to R&I investments in ECSEL that are in accordance with other policy measures such as standardisation or deployment and regulatory measures.
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

Further to the 8 objectives mentioned in the ECSEL Council Regulation, as mentioned in 1.1, the following approches can contribute to these objectives.

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.

The ECSEL contribution to a strong and competitive ECS in the Union is to execute projects that are based on all recommendations described in this MASP that 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 MASP, and the MASRIA[8] and its annexes that it is based on, contain an overview of the societal/technical demand and trends, justifying the selection of topics and highlighting the 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 as issued before 2018.[9] As basis for the MASRIA 2018, the newly developed ECS Roadmap 2017 (developed as a co-effort by AENEAS, ARTEMIS-IA and EPoSS - see [2]) is taken.

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.

[8] 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.

[9] 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.

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 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 technical 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.

Main output indicators

In the Interim Evaluation of ECSEL (see [3]) the topics above are seen as important and judged as well-addressed by ECSEL so far. In the report, an instructive picture, titled “Intervention Logic Diagram”, with the general objectives, specific objectives, JU activities, and main output indicaters is presented (see Figure 3).

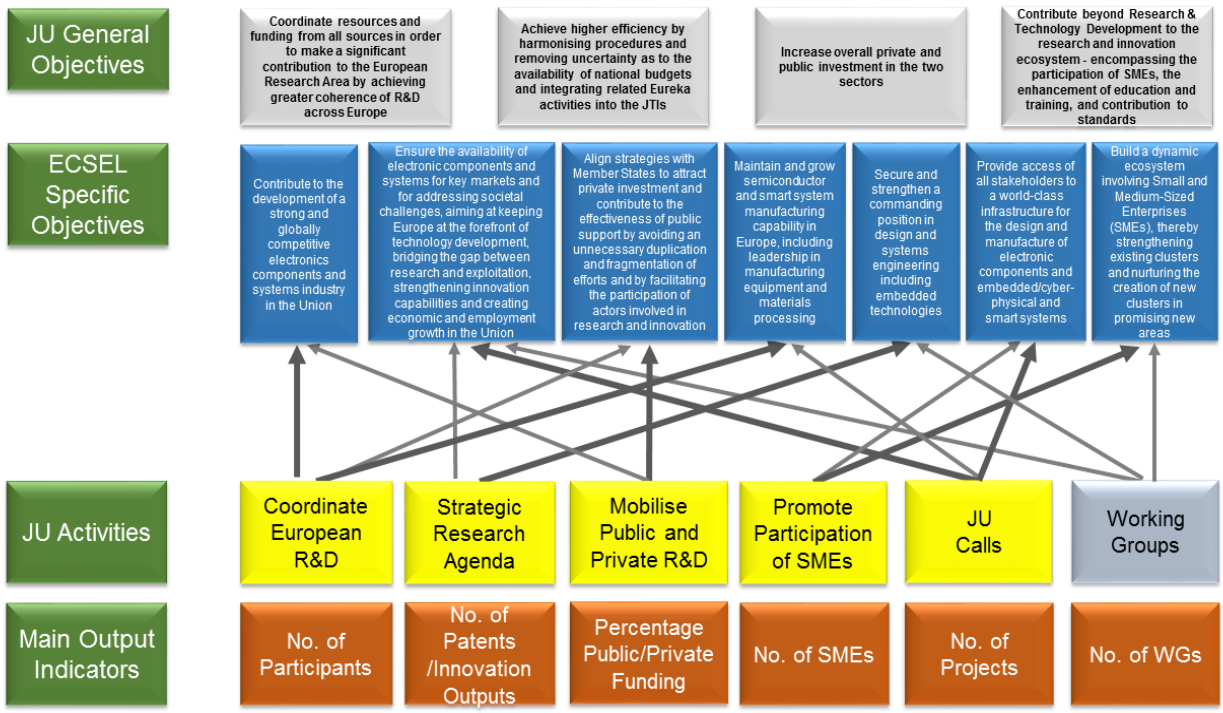


Figure 3 - Intervention Logic Diagram

The main output indicators in Figure 3 are quite basic, and will be further developed by the ECSEL Joint Undertaking office under supervision of the ECSEL Governing Board.

The Working Groups can be seen as a mix of working groups within the three associations and within the JU (i.e. Governing Board). Further the support groups of the Lighthouses (LIASE's) can be seen as working groups.

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. In this way, ECSEL is complementary to the other programmes.

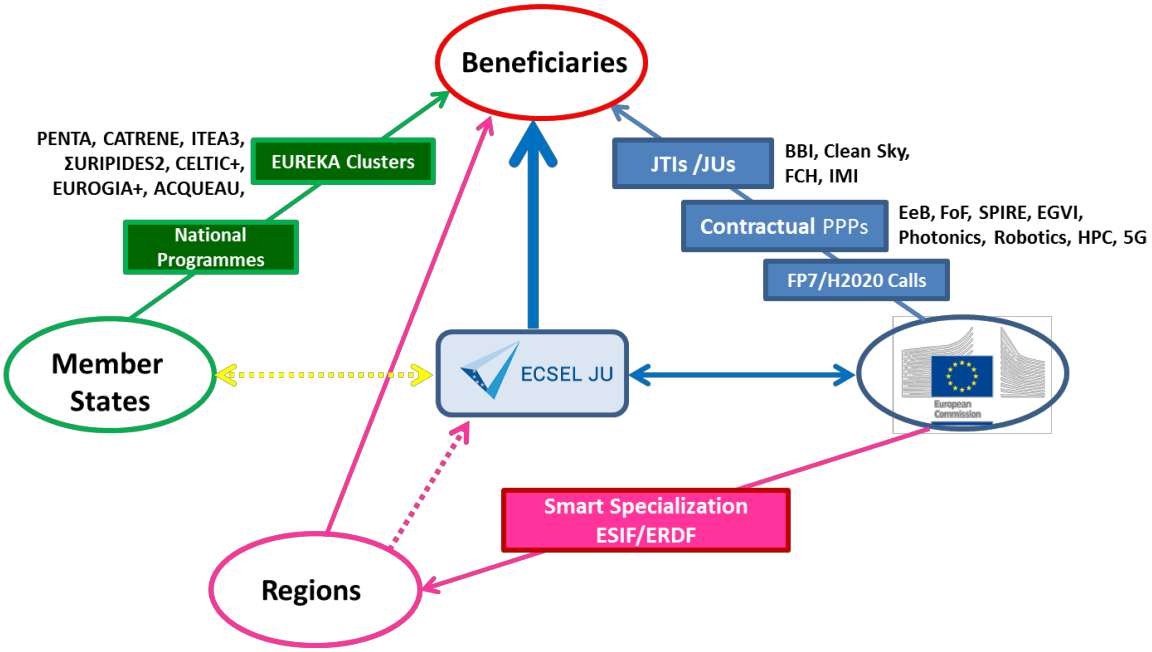


Figure 4 - ECSEL JU - the Tri-partite Joint Undertaking: one Mechanism among Many

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 should remain: One strategy – Two instruments. For EPoSS a constructive relation with Euripides can be mentioned. It is foreseen that the Lighthouses will contribute to the various cooperation levels.

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 Coordinations and Support Actions (CSA's) 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. A new approach should be to start CSA's funded by the ECSEL JU.

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."

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.[10]

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 [10]). 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 [10]) and create up to 800,000 jobs in Europe's ECS enabled ecosystem (see [4]). 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 [7]).

The importance of software is demonstrated in a survey of the EU; it was revealed that the R&D investments in software by the European industry was 53.9 % of all R&D investments in 2015.[11]

[10] Nano-Electronics and beyond 2020: Innovation for the Future of Europe (Nov. 2012).

[11] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/2015-eu-survey-industrial-rd-investment-trends.

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. Focus Areas

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 Focus Areas.

For each Focus Area 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 as explained in the ECS SRA.

Overall, this MASRIA focuses on a set of 5 key applications areas, and 5 essential capabilities, as depicted in the figure below. These market sectors represent all together over 50% of Europe GDP.

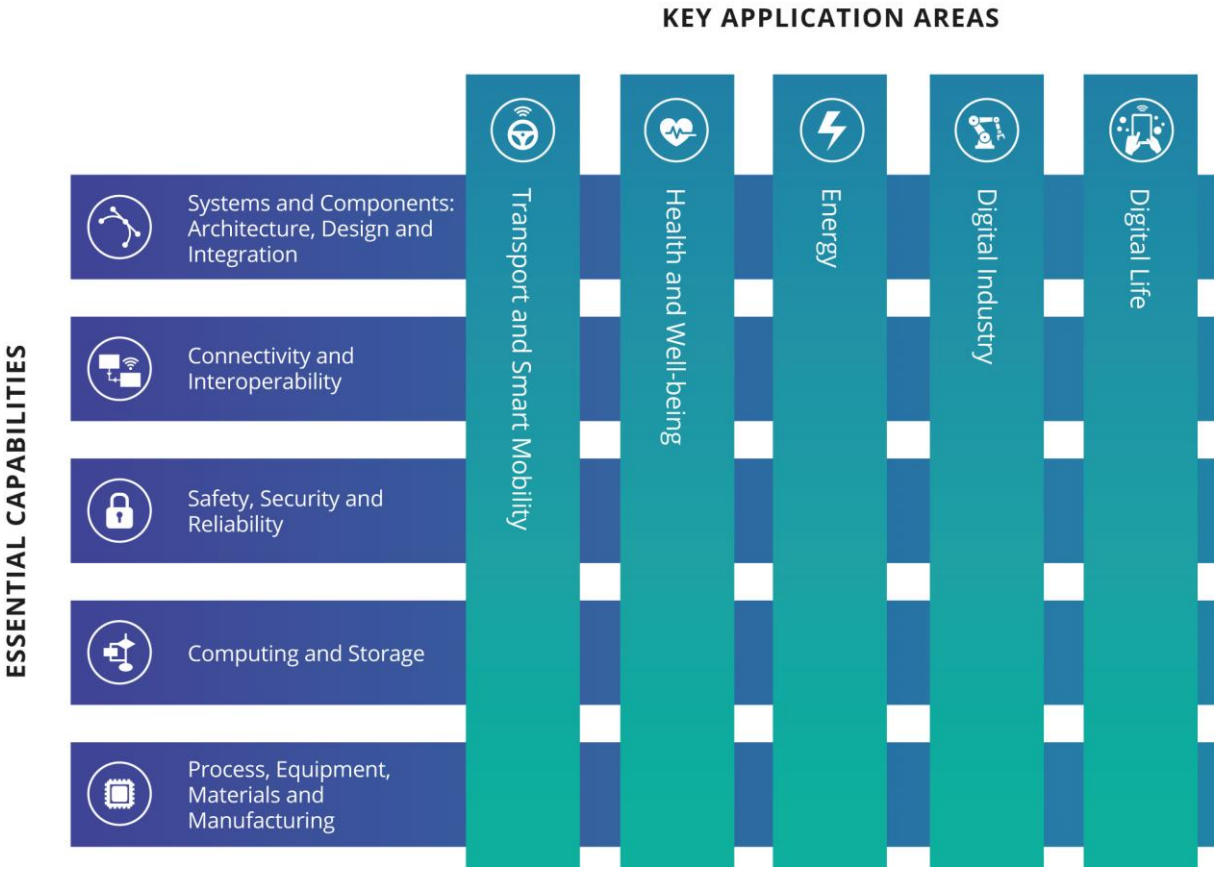


Figure 5 - Structure of the ECSEL Applications/Capabilities domain arena

Figure 5 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 Focus Areas capture and summarize the high-level priorities of the Private Members. 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 and via the Lighthouses with other initiatives. It is vital in creating initiatives of adequate critical mass and vital in fostering innovation that will contribute to the overall goals of ECSEL.

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 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 Focus Areas 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 (as previously in the ENIAC JU) and Innovation Pilot Projects (as previously in the AIPP's in the ARTEMIS JU) respectively.

Standardisation 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.[12]

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.

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 by the H2020

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

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 3 to 4);
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 5 to 8);
3) Using innovative technology;
4) Developing innovative solutions in relation with the ECSEL Focus Areas;
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 or use cases in sufficient volume/scale to establish their value and potential;
7) Having a deployment plan leading to production in Europe and worldwide commercialisation.

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.[13]

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.[14] [15]

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 clusters of 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 might give support on invitation or on request to those projects who’s impact is dependent on the successful implementation

[13] As in the ENIAC Pilot Lines.

[14] As in the ARTEMIS Innovation Pilot Projects.

[15] This concept also embraces real-life experiments by systematic user co-creation approach integrating research and innovation processes in Living labs.

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.

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 should be 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, or specific support for Lighthouse Initiatives, certain activities which are not fully 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. Generally, funding through Horizon 2020 actions (for example, CSAs) will be pursued,[16] [17] though the ECSEL JU may – in its Annual Work Plan for a given year - allocate some of its EU budget for specific CSA actions.

[16] An example is the much needed development of a roadmap for specification and standardisation of More-than-Moore equipment and materials.

[17] 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.

The ECSEL JU Work Plan for each year provides an overview of funding available in that year, while the relevant documentation for each Call for Proposals provides details of the funding available for that Call from each of the various sources.

5. Project selection and monitoring

ECSEL JU uses the procedures for evaluation, selection and monitoring as put down for the Horizon 2020 Programme. The funding decision, however, is the prerogative solely of the Public Authorities Board. The Decision ECSEL PAB 2016.23, adopted on 10.11.2016, including the rules on conflicts of interest, describes the process in full. This document is available on ECSEL JU website under DOCUMENTS.

ECSEL JU Multi Annual Strategic Research and Innovation Agenda

FOCUS AREAS:

Section 6 - 10: Key applications
Sections 11 -0: Essential Technologies

6. Transport & Smart Mobility

6.1. Executive Summary

The major Challenges in Transport & Smart Mobility are:

- Clean, affordable and sustainable propulsion
- Secure connected, cooperative and automated mobility and transportation
- Interaction between humans and vehicles
- Infrastructure and services for smart personal mobility and logistics.

These four major Challenges aim to keep Europe in the lead for innovations throughout the automotive value chain and to broaden the Research & Development & Innovation (RDI) horizon so that future research and innovation focuses more on holistic, cross-domain and sustainable mobility solutions for all the main transportation domains (Road, Rail, Aviation (incl. drones) and Maritime).

Key aspects to cover throughout the 4 challenges are increasing performance, security, privacy protection features, safety, sustainability, affordability, human interaction and societal acceptance. The defined Transport & Smart Mobility challenges not only address the most urgent Research and Innovation priorities in the sector, but also focus on developments that could be substantially driven by innovations in the European micro-electronics, nano-electronics and embedded systems industry in combination with the European IoT community.

6.2. Relevance

6.2.1. Competitive Value

Mobility is not only a visible expression of Europe's economic and societal prosperity; it is also an important source of that prosperity. Employing about 3 million people in manufacturing and another 11 million in services the transportation system is of high socio-economic relevance for Europe. Currently, the transportation sector is undergoing a fundamental and complex transformation across all modes. The European Commission's Strategic Transport Research and Innovation Agenda (STRIA) describing this transformation distinguishes seven transversal dimensions ranging from low emission, alternative propulsion system to smart mobility systems[18].

Connected cars are the first and important step towards highly automated and autonomous self-driving cars. Even though basic safety functions have to be provided by vehicle based sensor systems even if connectivity fails, the comfort and efficiency of automated operation will increase if additional information from other vehicles, dynamic maps and traffic management systems is available. Connectivity will be based on multiple protocols and standards, as e.g. camera's, vision systems, radar, Lidar, C2X 820.11p (G5), NFC, 5G, etc. It will also be of crucial importance towards connecting the car

[18] More about the competitive situation of European automotive industry can be found in the appendix to Chapter 1, section 11.1 "Competitive situation of automotive industry in Europe".

and the vulnerable road user. Security is a crucial issue that needs to be resolved prior to deploying large scale connectivity solutions.

The expected timeline is the following:

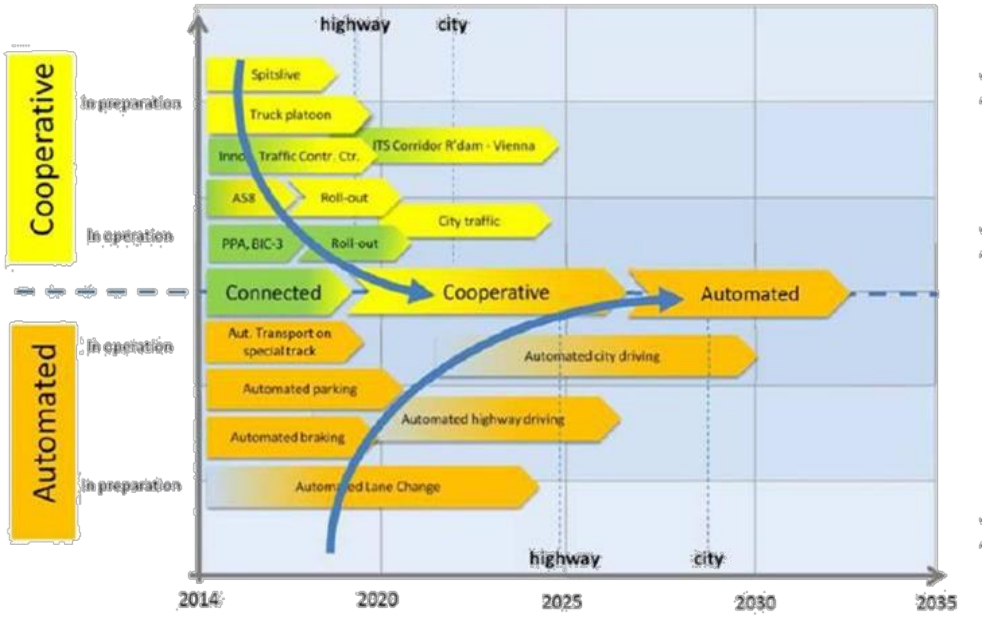


Figure 6 - Source: Gear 2030 Discussion Paper – Roadmap on Highly Automated Vehicles (Group E. C., 2016)

In the area of automated vehicles, the main challenge is the transition from niche market products to mainstream products. Three things must happen to enable a large market penetration of automated vehicles:

- there must be a large reduction in cost of the components, the embedded SW, the system integration as well as the validation effort
- the problem of homologation and validation of automated vehicles has to be solved
- A compatible road and traffic infrastructure has to be established

Vehicle automation can play also an important role in the success of electrified vehicles. The management of charging stations and driving to and from the charging stations can increase the societal acceptance as it is than easier to utilize especially expensive super-chargers without tedious waiting time from drivers.

The expert group in the European commission stated in a report *"that digitisation is currently reshaping the sector"* (Commission, STRIA Roadmap 3 - Smart mobility and Transport Services and Systems, 2017). Additional information about roadmaps on introduction of connected and automated vehicles can be found in (ERTRAC, New Automated Driving Roadmap, 2017).

6.2.2. Societal benefits

The EU-project "Action Plan for Future Mobility in Europe" (Mobility4EU) has identified and assessed societal challenges that influence future transport demand and supply. Societal trends, economic and political factors and stakeholder needs have been summarised in a context map (Mobility4EU, 2017).

Mobility is a subject that concerns everyone. It is a subject, that progresses of course rapidly in urban areas, but it is also concerns rural areas. Developing the right solutions for mobility across Europe can have a great impact on the overall image of Europe. Today, many people in the rural areas feel disconnected. They feel disconnected from mobility, from progress, from Europe. This feeling is at the origin of fatigue for the European case. The right developments can inverse this trend and bring all populations back on track.

The average age of the European population is growing constantly. In order to provide personal mobility to the elderlies, automation in transportation and smart mobility will play an important part to increase the quality of life. Fewer auto-related accidents and fatalities could reduce costs for emergency medical services and related legal fees. Furthermore, more time available through autonomous drive and shared smart mobility will increase consumption of multimedia and information and generally enhance the time spent in transit (Deloitte, 2016).

CO_2 reduction in transportation as agreed in the Paris treaty requires also significant advances in the automotive, maritime, aerospace electronics and embedded cyber-physical software technologies. Consumers and governments have more and more concerns about combustion engines; this forms an impetus to accelerate the exploration of new ways of propulsion, as e.g. hydrogen, electrical and other means.

6.3. Major Challenges

6.3.1. SWOT analysis

The table below presents a SWOT analysis on the current European position in Transport and Smart Mobility. These points are addressed in the individual major challenges and expected results.

	Positive factors	**Negative factors**
Internal factors to the EU industry[19]	**Strengths:** Presence of strong stakeholders in the automotive value chain in the EU Market leaders in rail & air in EU Many pilot sites for autonomous driving Great design capabilities and experience in semiconductors & embedded systems in EU	**Weaknesses:** High price & slow expansion of electrical cars in some countries in EU Limited cross-border cooperation Security & privacy threats could slow down the societal acceptance of autonomous driving
External factors to	**Opportunities:**	**Threats:**

[19] EU industry here means the full Large Industry + SME + RTO + University eco-system

	Advent of IoT, 5G and AI/Deep Learning will open new opportunities for future vehicles and other modes of transportation New mobility services and business models Electrification of vehicles Introduction of fuel-cell electrical vehicles	Competition from other continents (US: Tesla/Apple/Google & China local industry) Legislative requirements different in different continents

Figure 7 - SWOT analysis of European position in Transport and Smart Mobility

6.3.2. Major Challenge 1: Developing clean, affordable and sustainable propulsion

6.3.2.1. VISION

Road transportation alone accounts for 21% of Europe's fossil fuel consumption and 60% of its oil consumption. The increasing effect of the CO_2 emission as well as health-effecting gases as NO_x emitted by conventional vehicles motivates the global community to introduce new environmental friendly mobility. The Paris Agreement from 2016 (Nations, 2015) is an important international step towards a CO_2 neutral world. Several countries announced to ban the new vehicles based on ICE engines. An example is UK planning to ban them in 2040 (online, 2017). Electro-mobility will be based either plug-in batteries charged or H_2 based fuel cells as energy system. It will come strongly within the next 7 years to replace progressively traditional combustion engine driven cars. In parallel, conventional vehicles need more sophisticated sensors and software systems in order to reduce also their emissions and energy consumption in the interim period. Predictive maintenance and smart service concepts shall secure constant stable low emission and energy consumption levels over the life-time as well as the **availability of the vehicles** at reasonable costs. (Association E. I., 2017), (ERTRAC, Integrated Urban Mobility Roadmap, 2017)

6.3.2.2. SCOPE AND AMBITION

The scope of the development efforts covers all aspects including intelligent vehicles, optimal energy utilization, increase in energy efficiency (especially larger range for battery electrical vehicles), reduction of emissions from conventional combustion engines by embedded intelligence, reduction of costs, increased reliability, ….

This requires advanced embedded software taking advantage of new concepts as deep learning neural networks or model predictive control algorithms, advanced sensors and powerful, fast and energy optimized actuators (e.g. power electronics in case of electrified vehicles) to semi-conductor component level up to a full electronic system design. An additional challenge poses the validation of partially or fully electrified vehicles and their infrastructure (e.g. charging devices for battery electrical vehicles (conductive or inductive) for personal mobility or fully electric good transports over short and long distance) or hydrogen fuelling stations).

The smart usage of the additional information from the infrastructure or connected vehicles is another mean to reduce energy consumption and emission dangerous for the health of humans as well as increase safety and comfort for the passengers and vulnerable road users.

6.3.2.3. COMPETITIVE SITUATION AND GAME CHANGERS

Asia in particular is active in this area with Chinese, South Korean and Japanese car manufacturers and their related suppliers working on integrated solutions for electric and fuel cell based powertrains. Especially in H_2 based electrical vehicles, the first 3 commercial vehicles were introduced from far east companies. Furthermore, China has the target to become number one manufacturer of electric vehicles in some years and pushes its industry to accelerate the research on related technologies.

The US companies are more and more teaming up with the very large local IT giants working on electrical (and automated) vehicles. This can endanger the current leading position of the automotive industry in the future.

6.3.2.4. HIGH PRIORITY R&D&I AREAS

In order to achieve above ambitions, the following R&D&I topics have priority as they are enabling the efficient development of electronic components and their embedded software, which are the heart of in the clean, energy efficient transportation and smart mobility system.

New energy efficient system architectural concepts (EE as well as embedded SW)

As the automotive industry is in the transition from conventional internal combustion engine to hybrid, battery and fuel cell electrical powertrains, energy efficiency has several aspects for electronic components and systems as well as its embedded intelligence, the embedded software. The improvement of conventional powertrain concepts is also needed to already contribute to the CO_2 reduction during the transition period. New faster and more complex control algorithm are essential. The technologies and R&D&I tasks described in chapter 8 are in close relation to the R&D&I topics listed below.

The following R&D&I topics have to be addressed:

- Architecture for control systems of alternative powertrains
- Energy efficient electric/electronics/embedded-SW architectures (e.g. using energy harvesting, …) for alternative powered vehicles,
- Ultra-low power / high performance control units
- Higher energy efficiency of electrified vehicles (e.g. using higher frequencies of power electronics, better control software and advanced thermal management systems; the use of wide bandgap technologies)
- Improved / new safety concepts for high voltage powertrain systems
- Connected vehicles
- More efficient control algorithms conventional and hybrid powertrains to support the transition period to alternative CO_2 neutral mobility.

Filling/charging and energy & power storage and management

The successful adoption of electrification (either battery or fuel cell based) require the implementation of a charging/refuelling and energy / power management systems. Only if mainly

electricity of renewable sources is used, the desired positive impact of the transport sector to the CO_2 reduction will be achieved.

- ECS for efficient electrical or H_2 energy storage
- Electrical charging infrastructure and their smart control (conductive or inductive) for fully electric good transports over short or long distance as well as for passenger cars.
- Dynamic charging, charging-on-the-move
- Fully automatic high power (10x higher than today) and quick charging near highways

Control strategies and predictive health management

The electro-chemical or thermos-dynamical components as well as the advanced emission after-treatment systems are controlled by complex control systems. They are optimized to achieve the best energy efficiency will fulfilling other requirements as low emissions or protecting elements from overheating. The aging effects of those components change their behaviour over time significantly, thus decreasing the energy efficiency or other requirements. Therefore, predictive maintenance systems are necessary allowing optimal service interventions at lowest costs. Research in smart maintenance concepts will help to achieve those goals.

- Model predictive control algorithms supported by high performance multi-core real-time operating systems providing the necessary intelligence is another research direction.
- Energy efficient power management of electrical
- ECS for next generation of fuel cell electrical vehicles
- Predictive monitoring and diagnostics for electrical, hybrid or fuel-cell electrical vehicles to increase the lifetime
- Predictive maintenance for vehicles to reduce costs for the operation of vehicles

Smart sensors

Reduction in weight is another mean to increase energy efficiency. As the amount of electronics in vehicles exploded, the weight of sensor and communication cables increased accordingly. Wireless non-safety critical vehicular networks will have to improve significantly and guarantee highly dependable communication for distributed automotive, maritime, aerospace or rail powertrain systems.

- Development of smart sensors for the next generation of FCEV, Battery Electrical vehicles, Hybrid vehicles
- Integrated smart sensor systems to increase battery or fuel cell systems by individually control cells using smart sensors – e.g. Embedded sensors in batteries, fuel cells or exhaust after treatment systems

Smart actuators and motors in transport systems

Similarly, smart actuators and motors will decrease weight and contribute to the efficiency targets.

- Smart actuators for energy efficient powertrains

- New topology (multi-phase for improved availability) for e-motors with reduced amount of rare-earth materials.

6.3.2.5. EXPECTED ACHIEVEMENTS

The European supplier industry together with the OEMs and relevant research and development specialists need to get competitive and finally become a global leader in electrified propulsion.

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 (Association E. I., 2017), (ERTRAC, Integrated Urban Mobility Roadmap, 2017), (ERTRAC, New Automated Driving Roadmap, 2017)). 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.

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, 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 (JTI, 2014).

6.3.3. Major Challenge 2: Ensuring secure connected, cooperative and automated mobility and transportation

6.3.3.1. VISION

European transportation industries have to strengthen their leading position to provide sustainable solutions for safe and green mobility across all transportation domains (automotive, avionics, aerospace, maritime (over water as well as under water transport) and rail). Their competitive asset is a profound expertise in developing complex electronic components, cyber-physical systems, and embedded intelligence. Nevertheless, a bundle of challenges in terms of autonomy, complexity, safety, availability, controllability, economy, and comfort have to be addressed to harvest the opportunities from increasingly higher levels of automation and related capabilities.

By now, we are only at the beginning of an evolution of automated and autonomously acting machines. This movement is characterised by

- increasingly autonomous behaviour
- in increasingly complex and unpredictable environments
- fulfilling missions of increasing complexity
- the ability to collaborate with other machines and humans and
- the capability to learn from experiences and adopt the appropriate behaviour.

No single organization will be able to capture these tremendous efforts for research and development. In order to maintain a leading European position, it is therefore necessary to establish collaborations in and across industrial domains, learn from operational field data, and jointly drive the strategic actions.

The overall vision is to realize safe & secure always connected, cooperative, and automated transportation systems based on highly reliable and affordable electronic components and systems of European origin as well as technologies for new ways of interacting between humans and machines.

6.3.3.2. SCOPE AND AMBITION

Connected, cooperative, and ultimately automated mobility and transportation is seen as one of the key technologies and major technological advancements influencing and shaping our future quality of life. ECS will 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. Both development approaches – evolutionary (stepwise increase of automation level, “conversion design”) and revolutionary (SAE level 5, “purpose design”, e.g. people mover in structured environment) – should be covered as well as cross-fertilization with other industrial domains as Industry 4.0.

As the proportion of electronics and software as a percentage of the total construction cost of a vehicle[20] increases, so does the demand for the safe, secure, reliable and un-hackable operation of these systems. In addition, privacy protection is a key element for car owners and drivers/operators. These requirements ask for fail-operational technologies that deliver intrinsically safe operation and fail-safe fall-back from component to subsystem and provides a fall-back for problems in interaction with the cloud. This demands new developments in terms of multicore-/many-core-based platforms and sensing devices, combining advanced sensing in harsh conditions, novel micro- and nano-electronics sensors, filtering, advanced sensor fusion, noise reduction, fault detection, low power operation, self-testing and reliable predictable actuation.

Research, development, and innovation will focus on capabilities in the fields of sensing, communication, navigation/positioning, computing and decision-making, control and actuation based on smart systems for mobility and the necessary tools, methods, and processed for development and validation. Along with deterministic control strategies, data-driven algorithms based on artificial intelligence (AI) are covered in both ECS development phase and in-vehicle operation. It will be necessary to find new ways to perform fast and repeatable validation and non-regression tests independent from real-world tests.

6.3.3.3. COMPETITIVE SITUATION AND GAME CHANGERS

Especially in European countries, the mobility and transportation industry plays a central role for the internal market as well as for export markets. In the automotive sector - according to Europe’s

[20] The term “vehicle” includes cars, aircraft, trucks, vessels, trains, off-road vehicles, satellites, drones.

car manufacturers and transporters – around 12 million people (approximately 2.2 million directly and 10 million indirectly) are employed contributing 16 percent of the European Union's GDP.

However, competition is getting fiercer. Since 2013, China has overtaken Europe in number of cars produced. European car manufacturers are competing in a worldwide race toward vehicle automation and connectivity with newcomers from the IT sector. The value is being reshuffled across the value chains. According to several studies, 30 to 40 per cent of the value in the automotive value chain will pass through digital platforms, in the near future. Dependence on a reliable low latency IT infrastructure and its maintenance adds complexity to the value chain, and is an important issue to consider in order to realise the expected benefits of automation. If Europe safeguards its well-established market position by developing innovative and effective safety features, many jobs in the automotive, aeronautics and railway industries will be preserved as well as newly created.

6.3.3.4. HIGH PRIORITY R&D&I AREAS

The following research, development and innovations areas and their subtopics are identified (more details can be found in the Details to high priority R&D&I topics for Grand Challenge 2 in Application Chapter Transport & Smart Mobility":

- Environment recognition
- Localization, maps, and positioning
- Control strategies
- HW and SW platforms for control units for automated mobility and transportation (including also support for artificial intelligence)
- Communication inside and outside vehicle
- Testing and dependability
- Swarm data collection and continuous updating
- Predictive health monitoring for connected and automated mobility
- Functional safety and fail-operational architecture and functions (sensors, electronics, embedded software and system integration)

6.3.3.5. EXPECTED ACHIEVEMENTS

The impact of automated and connected vehicles could be huge. It could help to drastically reduce road fatalities and road accidents. New transport services could also be provided especially when the vehicle is provided with connectivity in addition to automation, e.g. traffic safety related warnings, traffic management, car sharing, new possibilities for elderly people or impaired people. Automation will also enable user's freedom for other activities when automated systems are active. Drivers/operators can expect more individual comfort and convenience which is likely to be the major motivation for upcoming automated driving. In the long term, automation could have a revolutionary impact on travel behaviour and urban development. It could also result in new

business models, such as shared and seamless intermodal mobility which could have an impact on the number of vehicles on our roads.

Connected, cooperative, and automated mobility also brings new challenges for regulators concerning road safety, security, traffic law, access to data, protection of personal data, financing, etc. which have to be addressed.

- Multiple innovative components and systems are expected for making highly secured automated and connected vehicles, including:
- Interacting information systems for safe and secure connection between vehicles and between vehicles and infrastructure, also enabling intelligent traffic/logistics management systems
- Intelligent on-board traffic management and navigation systems to achieve maximum efficiency and range/mileage
- Energy harvesting sensor & actuator systems in harsh conditions
- Next generation multi-core/many-core-based architectures
- Industrialization of AI-based systems
- Safe fall back vehicle sensing and actuation systems
- High precision low cost localization platform for civil use
- Fail-operational and 24/7 available ECS at low cost
- Methods and tools to virtually validate and approve connected, cooperative, automated vehicles

Development of such systems will be accomplished through the use of innovative new components and systems, methods and tools, and standards (e.g. sensors, embedded mixed criticality systems, actuators, communication protocols, etc.), new system-on-chip and system-in-package technologies, and new design/validation/verification methodologies on component and system level.

6.3.4. Major Challenge 3: Managing interaction between humans and vehicles

6.3.4.1. VISION

Vehicles are being more and more equipped with massive computing power, artificial intelligence, numerous assistance/ infotainment/ communication systems and partially autonomous functions. Individual transport has never been so distracting, easy and safe at the same time. One clear and shared vision of all industry branches related to transportation is that in the future there will be a broad variety of partially and fully autonomous operating vehicles, ships, drones, aircraft, trains, etc. In this world the exchange of information between humans and the technical systems is essential.

6.3.4.2. SCOPE AND AMBITION

The great challenge in this future coexistence of humans, “traditionally” operated vehicles and (partially) autonomous systems is the dynamic interaction between them: How does the human

know what the machine is going to do? How does the human tell the machine what to do and what not to do?

There is a clear demand for interfaces between humans inside and outside of such transportation systems and the technical systems which have to be: easy to understand, intuitive, easily adaptable, safe, secure, unobtrusive and reliable.

6.3.4.3. COMPETITIVE SITUATION AND GAME CHANGERS

With the rising number of capabilities of electronic systems also the number of possible use cases is rising. One example is the hype of speech recognition and home assistance systems, being pushed by Google, Amazon, Microsoft, Samsung etc. Adapting these solutions to the transportation sector is one of the next tasks to do.

6.3.4.4. HIGH PRIORITY R&D&I AREAS

The following research, development and innovations areas and their subtopics are identified:

- **Driver activities and vital signs monitoring:**
  (Partially) Autonomous vehicles have to know, in a non-invasive manner, the current status of the "driver" in order to notify adequately if any manual driving action needs to be done. This starts from e.g. the exact seating position and extends to monitoring the vital signs in order to be able to do emergency driving maneuvers in case of e.g. a sudden sleep attack (ref. Commission Directive 2014/85/EU regarding OSAS as a risk factor for driving), or a heart attack. Here the new generation of wearable sensing devices can play a role, being interconnected with the vehicle network.
- **Future human interaction technologies and concepts:**
  More and more functions in today's and even tomorrow's vehicles mean that an easy usage will be a great challenge. We need concepts and technologies to tell the technical systems what to do and what not to do. In addition to this we need ways for the systems to clearly tell/ show the humans what is happening right now, what will be happening next and which options there are. This is not restricted to persons e.g. sitting in an autonomous car but also includes all other road actors, e.g. pedestrians in the "world out there". This will need new components to interact between driver and automobiles, ships, airplanes etc. (haptic, optical, acoustic, … sensors).
- **"Online" Personalization of vehicles:**
  With "Shareconomy" and on-demand services getting more and more popular in the transportation sector there is a clear need for quick and easy individualization/ personalization of vehicles. We need concepts, technologies and systems which allow to adapt all functions and services of such a vehicle to the user/ passenger instantaneously.
- **Smart mobility for elderly, very young or non technical-affin people:**
  With an ageing society there is a clear demand for smart concepts which allow elderly people unlimited mobility. Seniority needs have to be considered for interaction concepts and systems.
- **Smart mobility for digital natives:**
  Digital Natives are used to always-on connectivity, digital interaction and fast information exchange. Concerning mobility there is the expectation of a seamless and instantaneous experience which can be fully managed by digital devices. Mobility clearly is a service.
- **Smart mobility for handicapped people:**
  Mobility for handicapped people needs special concepts which allow to adapt to various types of

physical and mental disabilities and ideally allowing these people to travel individually in a safe and secure way.

6.3.4.5. EXPECTED ACHIEVEMENTS

The expected outputs are described in chapter 6.3.4.4.

6.3.5. Major Challenge 4: Implementing infrastructure and services for smart personal mobility and logistics

6.3.5.1. VISION

An important future trend in transportation and mobility is the shift away from the paradigm of either exclusively personally owned or publicly operated modes towards integrated mobility solutions that are consumed as a service. Smart mobility services will establish more seamless, economic and sustainable mobility across all transportation modes in the smart cities of the future. This is enabled by combining transportation services from public and private providers through a unified IT platform and supported by jointly used physical and digital infrastructures. Both the transport of people and goods could be organized more efficiently in response to demand this way. The challenges to create smart multimodal spaces is covered in the chapter “Digital life - Major Challenge 4: Ensuring sustainable spaces”, the challenge to offer multimodal transport means is covered in this chapter.

6.3.5.2. SCOPE AND AMBITION

The solutions to be considered under this Major Challenge are manifold but highly depend on electronic components and systems; e.g. advanced V2X technology, traffic management systems, 2-/3-D navigation and guidance solutions in combination with mobility-as-a-service concepts will be fundamental to providing the optimal utilisation of new vehicle concepts for personal mobility and transportation in congested urban areas. These services will also be the basis for radically new mobility models – including robot taxis, shared self-driving shuttles and cooperative fleets of drones for last-mile delivery.

6.3.5.3. COMPETITIVE SITUATION AND GAME CHANGERS

Countries like Japan have already a communication infrastructure deployed that allows the development and full scale test of systems under real conditions. ECSEL needs such an environment to be able to develop competitive solutions. Regulations on V2X have e.g. pushed the development in the US to an acceleration.

V2X communication technology (ETSI ITS-G5 in Europe and US DSRC based on 802.11p) offers low latency short range communication in highly dynamic mobile environments, and is the basis for large scale deployments in several European countries. While the access layer technology has matured through extensive testing in the last decade, the main challenges in connected driving are vertical to the access layer: Safety-critical functions need to be ensured under security and privacy constraints. Services offered among infrastructure and vehicles need to discover in an ad-

hoc fashion and made available in a seamless and transparent way. Automation functions such as platooning require very robust short range wireless links with low latency. The same holds for guidance of vehicles by the traffic management and sharing of sensor perception between infrastructure and vehicles.

While the access technology is already available, communication protocols ensuring robustness and synchronization with other services using shared communication channels need to be developed, along with the methodology. Especially the mobility domain is characterized by highly dynamic, open and interconnected systems of systems, which requires design methodologies to develop protocols for such open environments, which require appropriate design methodology to ensure safety and security.

Single vehicle data enables the traffic management to obtain the traffic status on a very fine granularity, but also gather information about environment (local weather conditions, slippery road etc.). This can be seen as an evolutionary path from today's probe-vehicle data to comprehensive data allowing collaborative environment perception. Real-time data from infrastructure sensors will augment the vehicles perception capabilities.

Above technologies together with increasing difficulties to provide enough space for the increasing traffic especially in mega cities leads to radically new mobility concepts as mobility as a service. The paradigm shifts from owning the devices providing mobility to purchase only the services to move oneself or goods from one place to another. This requires new digital platforms and business systems to manage the mobility services with secure communication to the vehicles providing the mobility service.

The traffic management of the future needs to provide an optimal combination of different transport modes in response and anticipation of user demands. Traffic management will guide automated and non-automated vehicles. Road conditions, traffic situation, transport demands, weather conditions etc. need to be monitored in a fine-grained way using new infrastructure and distributed smart sensor technology including complex local pre-processing (e.g. machine learning).

New traffic sensor technology supporting robust fine-grained mobility detection. Combinations of several technologies such as high-resolution short-range radars, time-of-flight cameras might be a way forward. Guidance systems for truck platoons and automated vehicles require robust wireless links in real-time, fast and reliable detection by on-board and infrastructure sensors and reliable connection of this data, such that the central traffic management or a lead vehicle of a platoon can be sure to communicate and interact with the vehicles which are perceived by its sensors.

6.3.5.4. HIGH PRIORITY R&D&I AREAS

The following research, development and innovations areas and their subtopics are identified:

- V2x Communication
- Privacy by design

- Traffic management for single-modes (multi-modal traffic management is covered in the WG “Digital Life”)
- Management systems for multimodal transport means including necessary distributed smart sensors, interfaces, privacy protection, data management, traffic prediction, route optimization
- Guidance systems (remotely operated drones, trucks, ships,…)
- Mobility platforms for mobility as a service with seamless billing and payment systems (incl. e.g. personalized cards for users, usage of mobility services)
- Mobility as a (smart) service communication, security and privacy systems
- Predictive and remote maintenance
- Efficient logistics in freight and goods
- Vehicles offering services (also during parking) (e.g. WiFi extender, monitoring traffic density, airplanes acting as communication repeaters,…)
- Security and reliable availability of V2x communication

6.3.5.5. EXPECTED ACHIEVEMENTS

Development of further solutions for connectivity going from the individual car to the full system including infrastructure. This shall prepare the ground for the development of new services.

6.4. Make it happen

The stakeholders in the Industry Associations involved in ECSEL are capable of achieving the aforementioned goals because its members adopt a focused strategic approach that combines R&D competencies from across Europe and involves all stakeholders in the value chain. Most of the mentioned research topics will require several innovation steps in order to solve technological barriers and establish adequate price levels of the semiconductor, sensor and system components and necessary embedded cyber-physical software base. Therefore, the cooperative research in at different TRL levels will be necessary in order to achieve the necessary innovation speed required to keep the European industry in the field of transportation and smart mobility at the forefront in the world. The TLR level of RDI work depends always on the position of the research partner working on a task in the supply chain. Low level components typically have higher TRL levels than the application systems, into which they are integrated. Therefore, all task in the roadmap can be addressed by RIA or IAs.

Special attention will have to be paid to the interaction with legislative actions in this domain and societal acceptance of highly automated vehicles and new business models of future mobility. Furthermore, standardization will be crucial for future automated and autonomous cars, including the embedding of enhanced safety, security and privacy protection features.

Finally, governments will be needed to increase the amount of pilot test sites on both private as well as public grounds.

6.5. Timeframes

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
1 - Clean, affordable and sustainable propulsion	New energy efficient system architectural concepts (EE as well as embedded SW)									
	Filling/charging and energy & power management									
	Control strategies and predictive health management									
	Smart sensors									
	Smart actuators and motors in transport systems									

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
2 - Secure connected, cooperative and automated mobility and transportation	Environment recognition									
	TRL2-4, 4-6, and 6-8									
	Localization, maps, and positioning									
	TRL2-4, 4-6, and 6-8									
	Control strategies									
	TRL2-4, 4-6, and 6-8									
	HW and SW for artificial intelligence in automated mobility and transportation									
	TRL2-4, 4-6, and 6-8									
	Communication inside and outside vehicle									
	TRL 3-4 and higher									
	Testing and dependability									
	TRL2-4, 4-6, and 6-8									
	Swarm data collection and continuous updating									
		TRL2-4, 4-6, and 6-8								
	Predictive health monitoring for connected and automated mobility									
		TRL2-4, 4-6, and 6-8								
	Functional safety and fail-operational architecture and functions (sensors, electronics, embedded software and system integration)									
	TRL2-4, 4-6, and 6-8									

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
3 - Interaction between humans and vehicles	Driver activities and vital signs monitoring									
	TRL2-4, 4-6, and 6-8									
	Future human interaction technologies and concepts									
		TRL2-4, 4-6, and 6-8								
	"Online" Personalization of vehicles									
		TRL2-4, 4-6, and 6-8								
	Smart mobility for elderly, very young or non technical-affin people									
	TRL2-4, 4-6, and 6-8									
	Smart mobility for digital natives									
	TRL2-4, 4-6, and 6-8									
	Smart mobility for handicapped people									
	TRL2-4, 4-6, and 6-8									

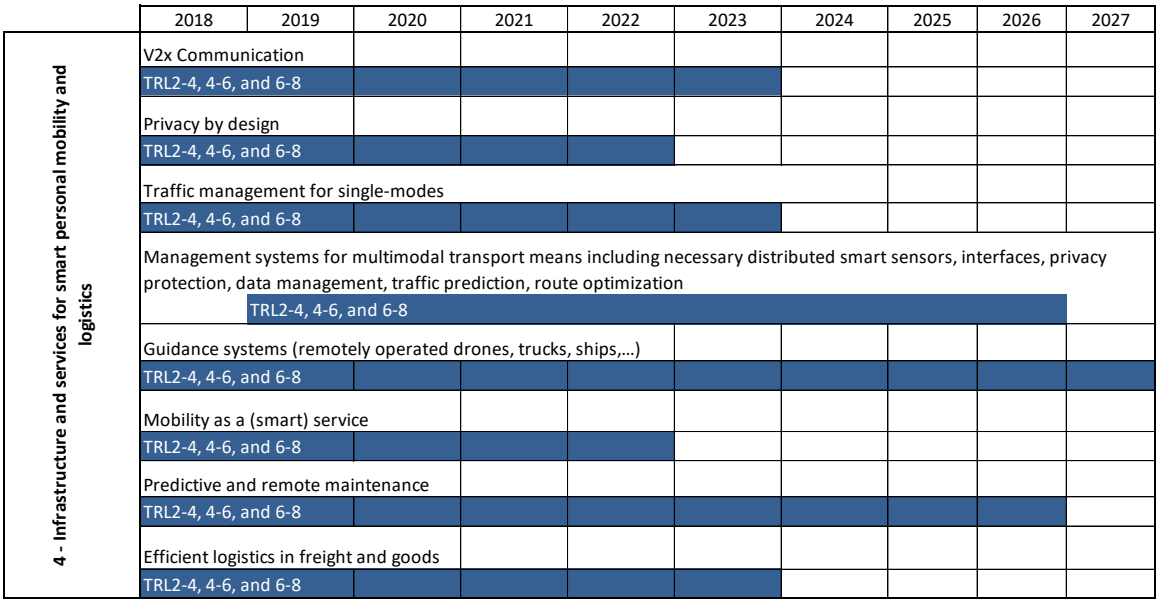


Figure 8 - Timeframes

6.6. Synergies with other themes

The widespread expectation of modern information and communication societies is that individuals take advantage of all existing services regardless of where those individuals are located – in the office, at home or on the move. Therefore, there is a synergy with the theme of **''Digital Lifestyle"**. Whereas "Digital Lifestyle'' will focus on the future life from a static point of view, meaning the citizen on a specific location or in a specific environment, the theme ''Transportation and Smart Mobility'' will focus on the dynamics and moving of the citizen in the society.

When moving to autonomous vehicles, the driver behaviour and monitoring will become more and more important. For that purpose, there is a synergy with the theme **''Health and Well-Being".** Within "Transportation and Smart Mobility'', seamless connectivity, interoperability and privacy protection become more and more important. This should be supported by cross-domain use of the themes of **"Connectivity & Interoperability''** and **"Dependability and Trustablity"**.

In contrast to other domains, Automotive & Transport applications are characterized by stringent real-time requirements and severely limited energy resources. To meet these requirements, robust technologies, components, simulation modelling & tools and domain-specific implementations of the same functionality are needed. Therefore, there is a synergy with the theme of **''From Systems to Components".**

7. Health and Well-Being

7.1. Executive summary

Healthcare systems face a huge challenge in providing the same level of care, in an appropriate, efficient and cost-effective way, to a rapidly growing and aging population. By 2030, the world population will have risen by 1.3 billion to 8.5 billion people; due to ageing, the world's population in the age bracket 65+ is projected to increase by 436 million to 1.3 billion people and the urban population by 1.5 billion to 5 billion, who all will require increased access to healthcare facilities and services.

Innovative technologies in health have long been integrated into devices that treat acute or chronic diseases, and which affect vital prognoses or alter drastically the quality of life of numerous patients. However, tremendous progress in research fields such as imaged guided interventions, genomics, bionic, biomedical, bio-sensing, regenerative medicine, energy harvesting and low-power electronics for communicating securely and extending processing and memory capacities now offer completely new approaches based on artificial intelligence, deep learning and the understanding of biological mechanisms at the origins of diseases that will radically change the way diseases are diagnosed, treated and followed-up. This is true for both professional healthcare as well vitality, wellbeing and prevention.

The way healthcare is provided is changing substantially, as medical interventions in the future are no longer confined to hospitals, clinics or medical offices, but are occurring anywhere in people's life, especially in their home. Ambulatory, "point-of-care" and "home care" are terms that will gain significance in the future.

This trend of "decentralized" healthcare will not only have an impact on how medicine reaches the patient, but will require a redefinition of the role and positioning of healthcare providers. ECS have the potential to provide suitable systems solutions, both to support the rising importance of personalized delivery of healthcare and to smarten existing healthcare providers and to assist the population in changing behaviors to improve their health.

7.2. Relevance

7.2.1. Competitive value

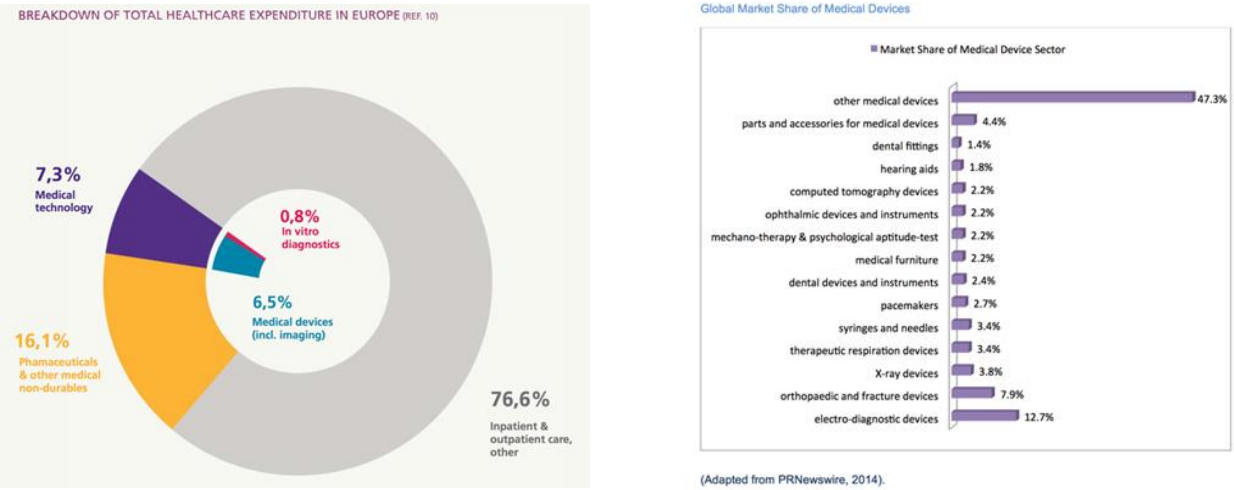


Figure 9 - Breakdown of total healthcare expenditure in Europe, Global Market Share of Medical Devices. There are 26,000 medical technology companies in Europe, 95% SMEs

In Europe, an average of 10% of gross domestic product (GDP) is spent on healthcare. Of this figure, around 1% of GDP is attributed to medical technologies. Expenditure on medical technology per capita in Europe is at around €197 (weighted average).

The European medical technology market has been growing on average by 4,6% per annum over the past 8 years.

EvaluateMedTech® consensus forecasts that the Medtech world market will achieve sales of $529.8bn in 2022, growing by 5.2% per year (CAGR) between 2015 and 2022. In vitro diagnostics (IVD) will be the largest device area in 2022, with sales forecast to reach $70.8bn. Cardiology takes the second spot, with annual sales increasing to $62.3bn in 2022. Neurology is forecast to be the fastest-growing device area, with a CAGR of 7.6% between 2015 and 2022.

The market of Image guided intervention and decision support will grow substantially. A complete new area is the connected care and Hospital informatics which will focus on workflow and digital solutions both in the hospital and other care facilities. The area of personal health will also grow considerable.

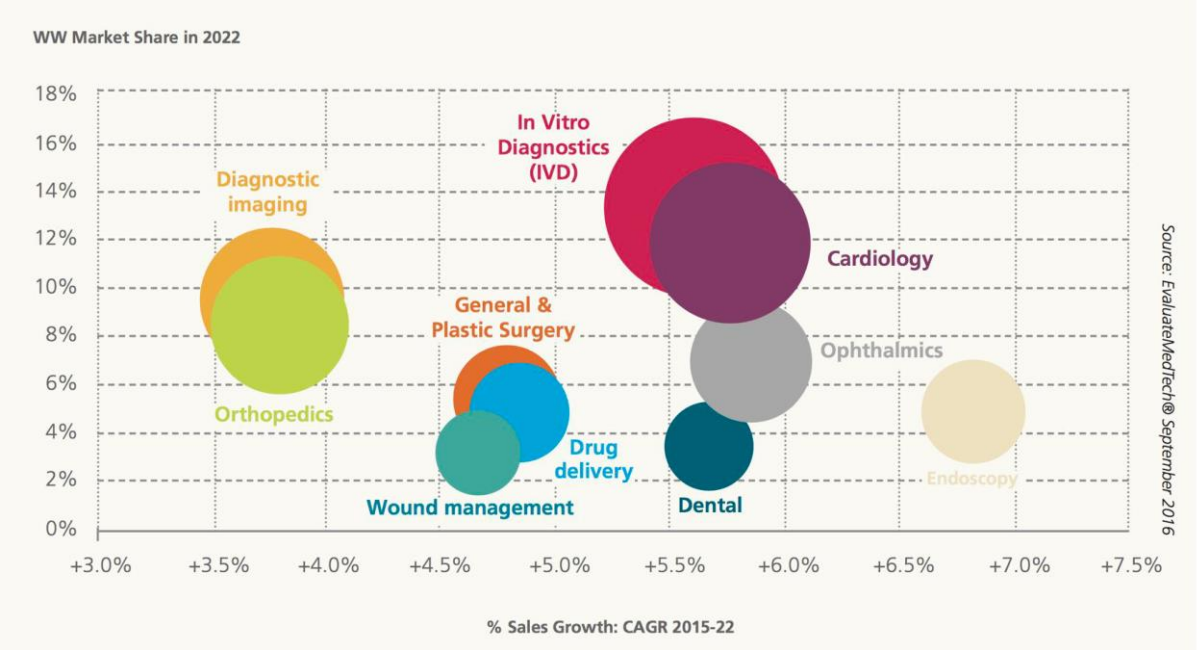


Figure 10 - Analysis on Top 10 Device Areas in 2022, Market Share & Sales Growth (2015-22)

The global home healthcare market is mainly driven by increasing geriatric population, rising healthcare costs and technological advancements in healthcare devices. With increasing health awareness among people, increase in a number of people diagnosed with chronic diseases such as diabetes cardiac disorders and respiratory diseases, the demand for home healthcare market is expected to grow in the near future. The population of geriatric people is growing rapidly across the world. Geriatric population is more vulnerable to non-communicable diseases such as diabetes. This, in turn, is expected to fuel the growth of home healthcare market. However, changing reimbursement policies and limited insurance coverage may pose a challenge to the home healthcare market growth in the near future. Rapid job growth decentral and especially in home healthcare services is expected open alluring avenues for the market growth over the next few years.

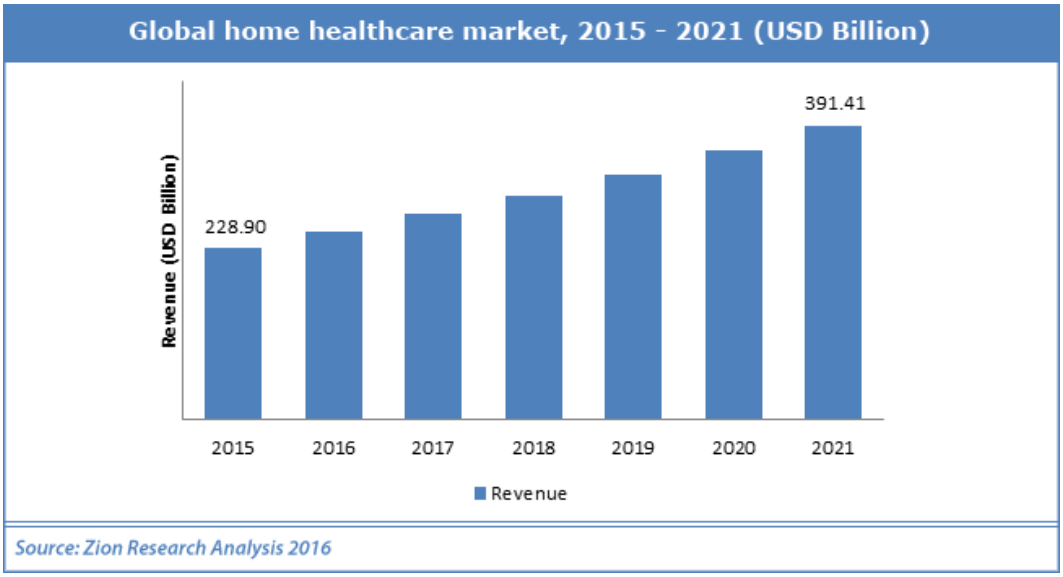


Figure 11 - Global home healthcare market 2015-2021

7.2.2. Societal benefits

The delivery of healthcare is in the process of "industrialization" in that it is undergoing changes in the organization of work which mirror those that began in other industries a century ago. This process is characterized by an increasing division of labour, standardization of roles and tasks, the rise of a managerial superstructure, and the degradation (or de-skilling) of work. The consolidation of the healthcare industry, the fragmentation of physician roles, and the increasing numbers of non-physician clinicians will likely accelerate this process. Although these changes hold the promise of more efficient and effective health care, physicians should be concerned about the resultant loss of autonomy, disruption of continuity of care, and the potential erosion of professional values. On the other hand, physician roles become more complex, because patients will be multi-morbid and can only treated by an integral approach to all disorders simultaneously.

Healthcare will also become more personalized. Personalized healthcare looks besides age, blood pressure, and cholesterol levels also at biological information, biomarkers, social and environmental information to gauge the risk of disease in individuals. Furthermore, it means providing individuals with tools like digital health and fitness apps, telemedicine providers, and at-home testing kits. These on-demand health solutions enable people to understand their health on their own terms, while receiving doctor input. Personalized health also applies patient-specific optimization of diagnostic imaging and image guided therapy and tailored settings of automated implanted medical devices based on personal data of an individual.

In many cases, bad-nutrition is a primary source of ill health significantly impacting on health expenses. For this reason, health policy-makers are now investing more resources in the early detection of causes of ill health related to food , rather than simply focus to its diagnosis and treatment. In such way, policy makers can possibly reduce the burden of food-related disease on the health services and improve the health of the population at large.

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 shorter hospital stays; safer and more secure access to healthcare information; relevant, correct and without information overload; better personalized prevention, information about environmental factors, diagnoses, management and treatment; improved quality of life and productivity; and reduced risk to further complications that could result from hospital treatment.

For healthcare professionals, benefits are directed towards improving decision support; providing safer and more secure access to healthcare information, precise and without information overload; 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 the 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, well-being 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 health prevention, a reduction of cost and a leaner approach to health care provision paired with an improved quality of treatment.

7.2.3. Game changers

To realise the above-mentioned benefits, we should focus on innovations and technologies which have the potential to become game changers in the health industry. The most important technologies are listed below:

- Cognitive computing.
- Transaction mechanisms for Data Security with Blockchain.
- Humanoid robots
- 3D Printing and Computerized Numerical Control machining
- Battery-free body worn or implantable medical device.
- Nano devices.
- Implantable organs on chip or implantable organs in package
- New (Bio) materials.
- Regenerative medicine.
- Imaging; Images will be combined with other sensor data to get precise models of the person's health. Precise imaging will be needed at many levels: from molecular imaging up to whole body imaging. This will be the main source of decision support for treatment and monitoring.

7.3. Major challenges

7.3.1. SWOT analysis

Below you can find a SWOT analysis on the current European position in healthcare. These points are addressed in the individual Major challenges and expected results

	Positive factors	Negative factors
Internal factors to the EU ECS industry[21]	**Strengths:** Presence of strong industrial players in EU (e.g., Philips, Elektra, Siemens, B Braun) Much creativity in EU Great design capabilities in EU Strong entire value chain Strong presence of small Medtech companies Good cooperation between universities, RTO, companies and hospitals Experience from past EU projects – pilot tests Leading position of Europe in MtM/sensor domain Strong, well developed mobile telecom with good territory coverage Health insurance systems in Europe are in general very elaborate	**Weaknesses:** Fragmented market across countries Limited start-up / VC culture Personalised cloud providers from US Fragmented solutions, no integrated solutions at hand Limited cross-border cooperation Necessity of multi-lingual solutions
External factors to the EU ECS industry	**Opportunities:** Move from hospitals to homes and care centers will enable high volumes Ubiquitous availability of smartphones will enable new ehealth services Low-cost availability of accurate health sensors will enable remote health monitoring Formulation of unified requirements concerning semantic interoperability and process interoperability will enable flexible modular solutions Availability of personal data enables new services and solutions European market is the largest in number of treated patients Faster market introduction due to EU directive on medical devices Similar cultural background in Europe might help in user acceptance Increasing demand of medical devices (prediction until 2022) Predicted growth of R&D expenses Ageing population results in growing market	**Threats:** Ageing population results in growing needs for integrated care Not all legislation uniform in EU Reimbursement schedules vary per EU member state Increasing competition from less fragmented markets Lack of widely accepted, advanced privacy and security technical standards

Figure 12 - SWOT analysis on current European position in healthcare

[21] EU industry here means the full Large Industry + SME + RTO + University eco-system

7.3.2. Moving healthcare from hospitals into our homes and daily life requiring preventive and patient centric care

7.3.2.1. VISION

Increasingly present-day patient functions move out of the hospital. In the end, only treatments and diagnoses that need large equipment and/or near presence of specialized medical personnel stay in hospitals that transform in treatment and/or diagnosis centres. Allowing mobile diagnoses and treatment systems enables specific procedures to move out of the hospital towards general practitioners or patient homes. In the meantime, the focus of healthcare (time spent and cost) is on embedding diagnosis and treatment in the hospital with home based prevention, monitoring and chronical disease management.

Patients become healthcare customers. They and their relatives are engaged in the prevention and care, and they are empowered to participate. This is supported by widespread connected care, integrating home based systems, and professional healthcare systems and information repositories.

Monitoring systems and alert systems are widely used to support prevention, diagnosis and aftercare. They are sensors and actuators to ensure precise and in time analysis and medical decision support.

Healthcare providers need to be proactive and address care customers and intervene before they notice their affected heath condition. Diagnosis and treatment are not bound to fixed places, but can occur near any place where the care customer is. Many chronic disorders will be treated at home with active implantable medical devices, which may be enhanced by body sensor networks. In addition to electronics, advanced biocompatible materials may be used as stimulator.

During treatment, the information gathering speeds up and delivers in real time the precise information needed to guide the treatment and involvement of higher care.

7.3.2.2. SCOPE AND AMBITION

Just products, or point solutions, are not sufficient anymore. Care solutions need to be holistic and integrated services, combining information across all phases of the continuum of care from many sources and preventing, preparing and providing care based on the person specific characteristics, taking co-morbidities into account. Predictive and preventative care is based on information originates from massive, and continuous individual's and population's data collection and analysis.

Given the aging of the population the incidence of co-morbity grows rapidly. To make electronic treatment with Active Implantable Medical Devices (AIMD's) viable, these AIMD's will have to coexist with each other within a single patient. Furthermore, coexistence between main stream diagnostic and therapy systems in hospitals and implantable devices shall be obtained.

An important aspect is to deal with the many different formats in which data is and will be collected. Because of the large variety in bandwidth and information range, and also the differences in age of the equipment, it is unrealistic to assume that all devices and sensors will use the same protocol. Therefore, analysis and decision support will be based on incoming information in many protocols.

7.3.2.3. HIGH PRIORITY R&D&I AREAS

- From products to integrated solutions and services
- Improved biomedical models of the health situation of healthcare customers, taking heterogeneous, longitudinal (image) data, context and population information into account
- Use large heterogeneous data from many sources to obtain precise information
- Ensure low latency analysis and reasoning involving 2D, 3D and 4D images, and prompt delivery of precise results, also in situations with partial and imperfect data
- Longitudinal monitoring and data analysis of many patients applying AI techniques, leading to precise alarms when needed, and only then
- Remote diagnosis and treatment delivery based on advanced user interaction models and collaboration models involving the healthcare customer and the healthcare practitioners
- Development of active or passive implantable medical devices for disorders currently not-treated or treated by life-long pharmacy (e.g. stimulators for spinal cord disorders, depression, obesity, hypertension)
- Development of novel regenerative medicine solutions
- Mutual coexistence between implants and main-stream diagnostic systems is a high priority research area with stretches from basic electromagnetic compatibility aspects to communication protocols and harmonized cloud analysis interfacing.
- Diagnostic imaging equipment with sufficient accuracy for active/passive implantable medical devices placement, preventing trial-and-error approach.

7.3.2.4. COMPETITIVE SITUATION

The current AIMD market is mainly governed by US companies Medtronic, Abbot and Boston Scientific. Nevertheless, in Europe a variety of start-ups, SMEs, Large enterprise and the presence of two major healthcare diagnostic players, Siemens and Philips lead to promising market expectations.

For regenerative medicine, there are no big players yet, but there are a large number of start-up companies active that are closely watched by the established industry.

Start-ups, SME are the most active players for introducing disruptive innovations in healthcare and wellbeing. Their innovation is worldwide industrialized and commercialized

by Large Companies. The close collaboration between Start-ups, SME and Large Companies is essential to strengthen of the eco system.

7.3.2.5. EXPECTED ACHIEVEMENTS

- Integrated solutions and services for specific disease groups, for customer groups, and for populations, covering parts of the care cycle
- Applicable biomedical models for specific disease groups, for customer groups, and for populations, covering parts of the care cycle, utilizing heterogeneous data involving history, context or population information into account
- Low latency (large image) data analysis and reasoning and dependable delivery of results
- Long term monitoring and data analysis of patients with chronic diseases, leading to decision support with a low level of false alarms
- Effective remote diagnosis and treatment delivery involving a collaboration between the healthcare customer and the healthcare practitioners
- High quality of life for patients with damaged of dysfunctional body parts, reducing lifetime costs
- More accurate (higher precision) diagnostic imaging

7.3.3. Restructuring healthcare delivery systems, from supply-driven to patient-oriented

7.3.3.1. VISION

Today healthcare costs are mainly based on demanding fixed prices for fixed, predefined, treatments at moments when the health problem is unavoidable disturbing the life of the patient. For chronic patients, the costs are determined by long-term pharmaceutical prescriptions and irregular treatments, when the disease gets severe. However patient centric healthcare demands prevention, early diagnosis before suffering, and continuous care in case of (multiple) chronic diseases. Outcome based healthcare will much faster predict the outcome of a disorder and its treatment for a patient. At its core is maximizing value for patients: that is, achieving the best outcomes at the lowest cost22. Not of the number of treatments, but the optimal value for the patients will become the driver of care. In addition, care centres will not be organized according to general hospitals that serve any disease. Instead, they will specialize to specified disease types, to improve the total outcome. These centres will not only act both on visiting patients, but increasingly, through remote access, to patients anywhere in the world.

7.3.3.2. SCOPE AND AMBITION

The goal of outcome based healthcare is to improve value for patients, without increasing the costs, and preferably lowering the costs. This demands that reimbursement schemes

[22] https://hbr.org/2013/10/the-strategy-that-will-fix-health-care

have to be changed, allowing more cost-effective care involving prevention, early detection and treatment, and continuous monitoring of chronical patients. Outcome based healthcare will learn and adopt optimization practices common in industry. The ambition is that due to outcome based healthcare predictability of diagnosis and treatment will be improved.

7.3.3.3. HIGH PRIORITY R&D&I AREAS

- Holistic health care involving all imbalanced health situations of the patient
- Use of the (growing) whole body of medical knowledge during diagnosis, treatment and monitoring
- EHR involving patient health models supporting precise communication between different care givers
- EHR involving health models that exactly describe the outcome heath values for the patients, both short term and long term
- Transform large healthcare systems to optimize hospital workflow, automatically optimize diagnostic imaging and tracking of therapy results, enable preventive maintenance and generation of requirements and test cases for new generations of systems
- Predictable and repeatable outcome of diagnostic imaging. Current diagnostic imaging is often of qualitative nature, meaning that comparison over time or with other patient cases is impossible
- Apply generic standards (e.g. industry 4.0) to diagnostic and therapy systems and use of big data principles to reduce cost of ownership
- Less harmful and less expensive imaging modalities (like ultrasound) at several levels: from molecular imaging up to whole body imaging, in the prevention, diagnosis, therapy and monitoring phases
- Humanoid robots applying interpreted human body language and emotion in care delivery.
- Robotics to improve treatments either in the operating room, minimal invasively inside the body, at general practitioners or at home
- 3D Printing and CNC (Computerized Numerical Control machining): Printing implants and prosthetics for individuals, create patient-specific anatomical models, e.g. create powered exoskeleton to help paraplegics to walk again

7.3.3.4. COMPETITIVE SITUATION

Two of the three major diagnostic imaging and image guided intervention companies (Philips and Siemens) are based in Europe. Competition from China (e.g. United Imaging) and Korea (Samsung) is emerging, driving the need for faster innovation at lower cost in Europe.

7.3.3.5. EXPECTED ACHIEVEMENTS

- Health care delivery for patients with co-morbidities
- Preventive and early warnings for (combine) diseases
- Image analysis and decision support for diagnosis, treatment and monitoring, using large medical knowledge bases
- Quantitative, less harmful and less expensive imaging for diagnosis and therapy
- Patient health models on complex heath conditions
- Outcome based treatment, diagnosis and monitoring health models
- Healthcare systems, IoT with big data learning for optimizing workflow, usage, capabilities and maintenance
- Repeatable and quantifiable outcome of diagnosis (including the use of biomarkers) and treatment

7.3.4. Engaging individuals more actively in their own health and well-being

7.3.4.1. VISION

In 2030, digitalisation will be common in our society, and will bring healthcare from clinical centres into the everyday life of the citizen, in health and vitality promotion as much as for healthcare and disease prevention. Highly motivated individuals will improve their vitality by using wearables and connected software, thus enabling adjustment of personalized models that make them increasingly aware about the impact of body movement, food and nutrition on their health. The development of digital health ecosystems (comprising digital health platforms, health monitoring wearables and devices, mobile applications and online services) will empower individuals to monitor against a norm, manage, track and improve their own health. This will open new markets of solutions and services directly targeted to both healthy and patient individuals, and positively impact on the effect of preventive practices as well as on the application of treatments earlier.

7.3.4.2. SCOPE AND AMBITION

Motivated and educated population will take preventive measures. Collection of long-term data will contribute to early capture of a disease or disorder, which will increase probability of fast and successful treatment.

The ecosystem of healthcare solutions targeted to the individuals is growing fast. The competition is pushing the improvement of features provided and quality of service as well as the specialization. Smart algorithms for different purposes will be developed and specialized marketplaces will emerge; data analytics demand and offer will push the creation and sharing of data sources; precision medicine will follow the two previous building blocks.

7.3.4.3. HIGH PRIORITY R&D&I AREAS

- Wearables or minimal invasive implants, Internet of Things, simple analysers for home use; reliable data collection and analysis – focus on input data quality assessment (we need to know whether we evaluate useful data or noise and artefacts); standardization of calibration, process interoperability
- Devices or systems for utilizing/extracting/sharing new knowledge in the most informative and efficient manner (e.g. vitality data, molecular profiling, biotechnology, diagnostics, ICT tools) in the most appropriate personalized setting (e.g. health care system, at home)
- Devices or systems for protecting and enforcing individual health-related information: ownership and secure storage of health data, data sharing with healthcare providers, and real-time anonymization for wider data analytics Devices or systems improving security for executing transactions in healthcare and wellbeing, like blockchains to improve health or personal records exchanges and interact with stakeholders
- Devices or systems for integration of health and prevention ICT solutions in national health systems.

7.3.4.4. COMPETITIVE SITUATION

- A major development in the wearable technology and devices market is quickly becoming popular. According to a research report conducted by Transparency Market Research indicates that the wearable devices market, or the remote patient monitoring devices market, is anticipated to reach US$0.98 billion by the end of 2020. This represents a growth of 14.2% CAGR rate. Top players are Biotricity Inc., Abbott Laboratories, Apple, Alphabet, Business Machines Corp.
- Three groups are fighting a war for control of the “healthcare value chain”.
- One group comprises “traditional innovators”—pharmaceutical firms, hospitals and medical-technology companies such as GE Healthcare, Siemens, Medtronic and Philips.
- A second category is made up of “incumbent players”, which include health insurers, pharmacy-benefit managers (which buy drugs in bulk), and as single-payer healthcare systems such as UK NHS.
- The third group are the technology “insurgents”, including Google, Apple, Amazon and a host of hungry entrepreneurs that are creating apps, predictive-diagnostics systems and new devices. These firms may well profit most handsomely from the shift to digital.

7.3.4.5. EXPECTED ACHIEVEMENTS

- Repeatable and quantifiable outcome of vitality and prevention.
- Early diagnostics based on assessment of longitudinal patient data.
- New models of person-centred health delivery, also integrating health and social care and considering the environment and community setting of the individual. Transition to a decentralized model, from traditional health care venues like hospitals to integrated care models (e.g. transfer of records to patients);
- Empowerment of the individual to manage his data: individuals taking greater ownership of his/her state of health, especially for those with chronic conditions.

7.3.5. Ensuring affordable healthcare for the growing amount of chronic, lifestyle related diseases and an ageing population

7.3.5.1. VISION

Most of the chronic and lifestyle related diseases and elderly diseases need long-term monitoring of the patient state and support for rehabilitation. Current rehabilitation and physiotherapy is labour demanding, thus the machine supported rehabilitation and physiotherapy could contribute to higher efficiency of the work.

According to several foresight studies[23], in 2030 priorities will lie with promoting healthy lifestyles, preventing illness and curing promptly while supporting vulnerable people and enabling social participation.

7.3.5.2. SCOPE AND AMBITION

Modular rehabilitation devices with intelligent real-time feedback to the user can enhance the efficiency of treatment. Gamification of the interaction may contribute to motivation of the user. Modularity of the devices allows for personalization of the treatment. Basic components will be built on Industry 4.0 principles.

7.3.5.3. HIGH PRIORITY R&D&I AREAS

- Wearables or minimal invasive implants, including new sensor systems for easier and more efficient measurement of physiological parameters, incl. posture, sitting position, physical activity, dynamics of walking, etc
- Devices or systems using biomedical models for better diagnostics, therapy and feedback to the patient for several chronic diseases e.g. musculoskeletal system and simulation of activity of muscle groups, joints, etc.
- Devices or systems using predictive models to anticipate the appearance of co-morbidities because of the evolution of chronic diseases
- Real-time location services with badges that can track patients, staff and medical devices, Environmental monitoring — for example, checking hand hygiene compliance. Mobile apps will replace traditional physician visits

7.3.5.4. COMPETITIVE SITUATION

Few companies exist that focus on development of precise models, e.g. Dassault systems. In the area of rehabilitation there are companies producing exoskeletons, e.g. ReWalk, Cyberdyne, Ekso Bionics Holdings.

[23] National Institute for Public Health and the Environment (2014) A healthier Netherlands: Key findings from the Dutch 2014 Public Health Status and Foresight Report. RIVM, Netherlands.

7.3.5.5. EXPECTED ACHIEVEMENTS

- Focus on wellbeing and prevention to identify trends towards ill health and so strive to keep people away from unnecessary care and to encourage them to be proactive
- Person-oriented approaches for the treatment of patients with multiple chronic diseases, situations of frailty and/or of loss of functionalities in a multi-cultural context
- Individuals taking greater ownership of his/her state of health, especially for those with chronic conditions
- Modular systems adjustable to individuals´ needs. Gamification will increase motivation of the patients

7.3.6. Developing platforms for wearables/implants, data analytics, artificial intelligence for precision medicine and personalized healthcare and well-being

7.3.6.1. VISION

In 2030, technologies such as wearable devices, remote diagnostics, tele-medicine and personalized medicine will be successfully developed to reduce inefficiencies and improve access to healthcare, with apps providing innovative platforms. These devices will generate enormous volumes of data. The role of digital health platforms, wearables or minimal invasive implants and mobile devices will evolve beyond remote health monitoring and reporting towards smarter tools able to make early decisions, both for medical professionals and the customer and his/her relatives, especially in cases where a quick action is needed (e.g. brain stroke prevention). This will enable new approaches to early disease detection, prevention and treatment, paving the way for personalized treatments.

Furthermore, professional data and data originating from person's wearables or minimal invasive implants, environmental sensors will be integrated into relevant information about the health condition of the person. This information will become the main source of decision support that triggers caregivers and the person themselves about endangering heath situations. Health measurements will combine both cheap retail products, sensors and certified health care measuring devices. Dependent on the person's condition, more or less certified products will be used.

7.3.6.2. SCOPE AND AMBITION

Mobile devices and wearables will leverage advances in diagnostics, integrating sensor scanning, data recording and data analysis. New pharmaceuticals and treatments will be developed for personalised medicine settings, by embedding connected devices and exploiting the potential of IoT and AI. AI (machine-learning, deep learning and related) will be the key differentiator for any smart health device. Smart algorithms and specialized predictive models will be developed, emerging specialized marketplaces. Data analytics demand will push the creation and sharing of data sources, as well as the development of mechanisms (e.g. distributed ledgers) to protect the transmission of health data records across the healthcare value chain.

The aim is to deliver preventive and early care to everybody wherever they may be based on personalized models. Care is provided by combining many sensor inputs, personal historical information and analyzing it according to their healthcare merits.

7.3.6.3. HIGH PRIORITY R&D&I AREAS

- Smart, robust, secure and easy to use devices or systems (wearable or implantable and autonomous) for detection, diagnostic, therapy, through big data, artificial intelligence, machine learning, deep learning person-centred
- Multi-modal data fusion devices or systems: the generation of enormous amounts of data from different sources (e.g. vital signs from mobile apps, home monitoring, real-time sensors, imaging, genomic data, pharmaceutical data, and behavioral markers) brings valuable information to improve clinical decisions and to reveal entirely new approaches to treating diseases. But the fusion of multi-modal data poses several technical challenges related to modelling, data mining, interoperability, data share keeping privacy
- Scalable platforms able to support automatic deployment and maintenance of applications for digital health, guaranteeing Service Level Agreements and Security for data
- Energy efficiency for medical wearables/implants: Improvement of energy consumption and battery life at device levels. Ability to deliver connected devices (wearable/implants) that are self-sustainable from an energy point of view for the full duration of a medical treatment (weeks, months or years)
- Sustainable, renewable or harvested long term highly integrated energy sources or devices
- Upgradability of medical wearables/implants: A wearable/implant must be able to work on several configurations in function of the disease evolution and the treatment improvements. The upgrade/downgrade can't imply the wearable/implants obsolescence. Therefore, supporting wearable infrastructure should support the possibility of running virtual complementary devices to complement the processing power and storage embedded in wearables/implants
- Highly dependable (reliable, secure, safe, privacy supporting, easy to use, …) IoT platforms
- Devices or systems data with low latency analysis performed with deterministic algorithms or deep learning that are able to deal with known levels of trust (both high and low) for precise presentation of the results to medical professionals and non-professionals
- Devices or systems based on cognitive computers providing support to professionals or non-professionals for healthcare or wellbeing

7.3.6.4. COMPETITIVE SITUATION

The digital health market is fragmented geographically, with large companies, local small players and startups competing together in different regions. Globally, North America is expected to keep accounting the highest market share (being US the dominant market in

this region), followed by Western Europe (Germany) and Asia (China)[24]. Major global players include European companies (Philips, Siemens, Lifewatch, Bosch Healthcare, SAP), although U.S. companies dominate the global landscape (GE Healthcare, Qualcomm, McKesson Corporation, AT&T, IBM, Cerner Corp., Cisco, eClinicalWorks, athenahealth), followed by emerging competitors from China (iHealthLabs, Alibaba Health Information Technology, Tencent, Baidu). Major IT technology players are also positioning in the market, with solutions leveraging data analytics: IBM, Microsoft, Google, Apple and Amazon.

7.3.6.5. EXPECTED ACHIEVEMENTS

- Better understanding of treatment response and prognostic heterogeneity. More refined, patient tailored, approaches to disease detection, prevention and treatment
- Better integration and analysis of multi-modal data, providing new tools for clinical decision-making and precision medicine. Development of dynamic healthcare systems that learn in real-time from every result
- New technologies for early diagnostics, personalized medicine, and potential curative technologies (e.g. regenerative medicine, immunotherapy for cancer). Development of a wider European market offer of wearable and mobile devices for healthcare
- Repeatable and quantifiable outcome of diagnosis and treatment. Adjustment of treatment based on intermediate/continuous data evaluation.
- Dependable IoT platforms
- Models for levels of trust of sensor data and data quality
- Low latency analysis algorithms that are able to deal with known levels of trust (both high and low) of sensor data
- Presentation of analysis results to medical professionals and healthcare customers

[24] Global Market Insights: Digital Health Market forecasts 2016-2024. November 2016.

7.4. Timeframes

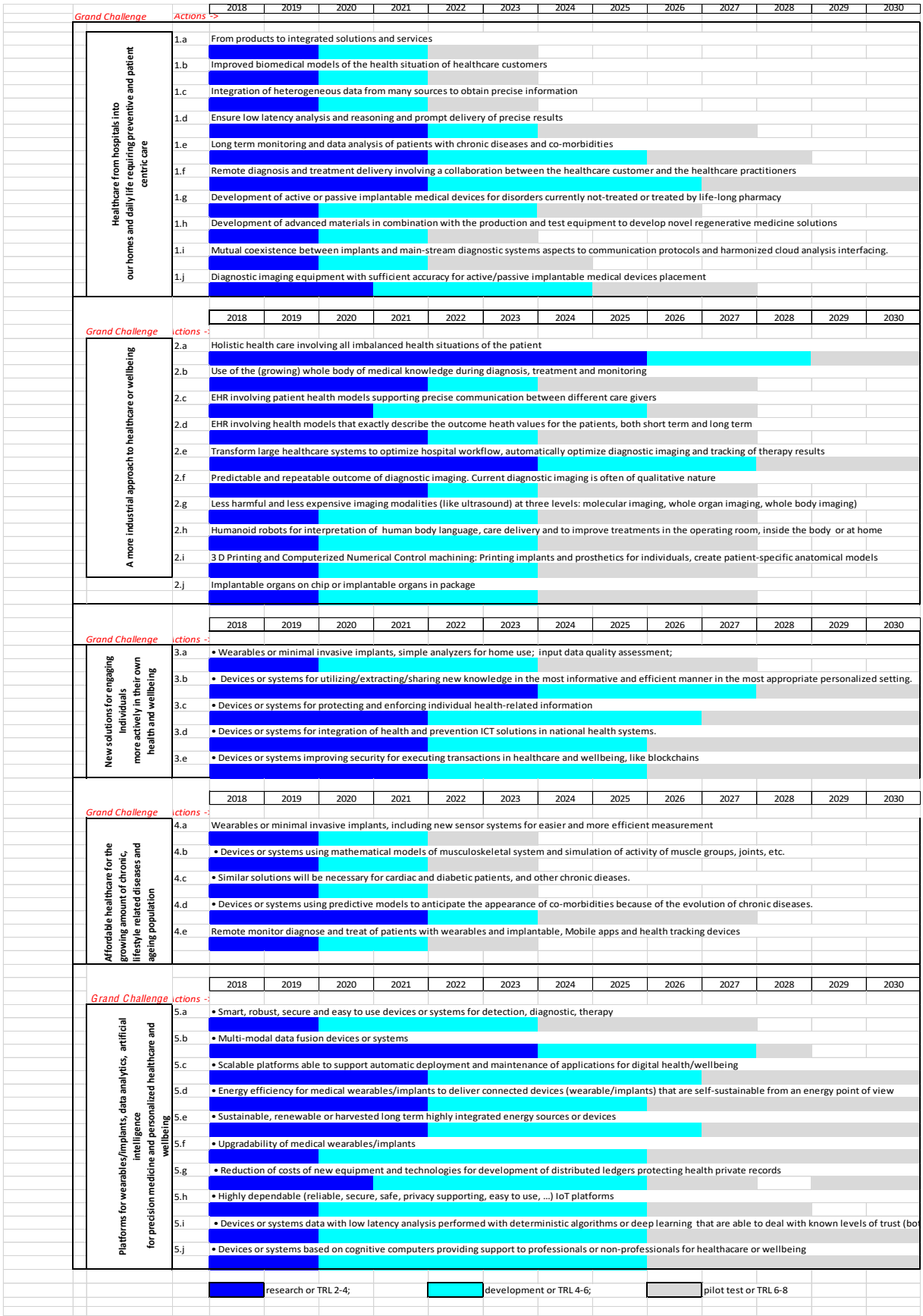


Figure 13 - Timeframe 2018-2030

8. Energy

8.1. Executive Summary

The energy world is in transition: different energy sources are linked to achieve high efficiency, reliability and affordability. The growth of renewable energy sources such as solar and wind power are changing the nature of the world's power grids. The increasing distribution of power generation leads from today's unidirectional to a distributed and bi-directional power flow. This situation requires intelligence and security features at each level of the grid and 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 institutes, 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.

Significant reduction of primary energy consumption along with the reduced carbon dioxide emissions is the key objective of the Energy chapter. 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 and in embedded and integrated systems to secure the balance between sustainability, cost efficiency and security of supply in all energy applications.

8.2. Relevance

8.2.1. Competitive Value

In the last years, it has become apparent that semiconductor-based innovative technologies have enabled more savings of electrical energy than the growth of demand has been in the same period. The core of the European competitive advantage is within the system knowledge and provision of holistic system solutions. Saving energy is equivalent to reducing the costs and being more competitive. Energy efficiency levels in IEA member countries improved, on average, by 14% between 2000 and 2015. This generated energy savings of 19 exajoules (EJ) or 450 million tonnes of oil equivalent (Mtoe) in 2015. These savings also reduced total energy expenditure by 540 billion USD in 2015, mostly in buildings and industry. While GDP grew by 2% in IEA countries, the efficiency gains led to flattening of the growth in the primary energy demand. In parallel, the global CO2 emissions stalled since 2013 with only 2% growth, in 2014 with 1,1% and in 2015 with -0,1%.

Energy saving is also an opportunity. In fact, by reducing power dissipation and corresponding heat production, energy is available for other uses and equipment.

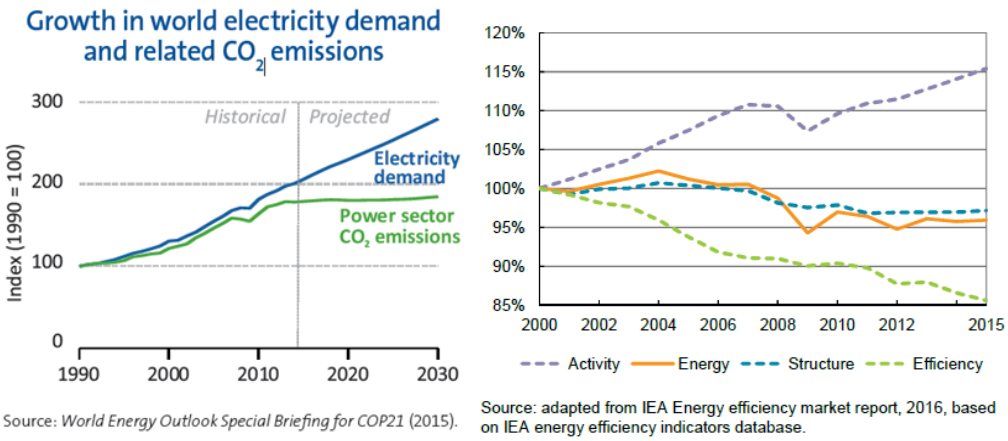


Figure 14 – Growth in world electricity demand and related CO2 emissions

According to IEA, the analysis of factors driving energy consumption trends for IEA member countries indicates that in IEA the decoupling was mainly due to efficiency improvements (figure right above). Structural changes (mostly shift to less intensive industries and services) also assisted efficiency improvements in reducing the total energy consumption. Cumulative savings over the period 2000 – 2015 were 159 EJ, equivalent to more than one year of final energy consumption in Europe, China and India altogether[25].

Examples of the most important ECS applications having high impact on the efficient use or generation of energy are power inverters – the steadily growing market (65 Bill. US$ forecasted for inverters in 2020). The corresponding value chain is shown in the figure based on data from a Yole report [26].

Another example of ECS market contributing to the efficient use of energy is the wireless infrastructure RF power device market, with around US$1 billion TAM. The share of GaN based devices increases from 10% in 2015 to expected 40% in 2022 (source ABIresearch, 2017) which demonstrates how fast new techniques can be deployed if the business added value is achieved. Driven by new developments, such as the electro mobility and Industry 4.0, new energy supply chains and consumption patterns come up. Powering the electro mobility is a major challenge in the coming years with the implementation of a reliable and sustainable charging infrastructure.

The potential of the upcoming industrial era 4.0 is based on the combination of two novel technologies: Cyber-Physical Systems (CPS) and the Internet of Things (IoT). Higher efficiency at all levels in power usage is one enabler for Smart Industry: Power conversion & energy harvesting, Power Management, Power storage & Motor Control (see next figure).

[25] Energy efficiency indicators by OECD/IEA – Highlights 2016

[26] Power Integrated Circuit 2017 - Quarterly Update – Yole Développement

Figure 15 - Industrial 4.0 example, source Hannover Messe conferences

European ECS companies are amongst the leaders in smart energy related markets, which is largely driven by political decisions as well as by the move to renewing energies and to added costs on carbon dioxide emissions. Leading market positions are achieved for electrical drives, grid technology and decentralized renewable energy sources. This position will be strengthened and further employment secured by innovative research on European level. Competitive advantages can be gained by research in the following areas:

1) significant reduction and recovery of losses (application and SoA related);
2) power density increase and decreased size of the systems by miniaturization and integration, on system and power electronics level;
3) increased functionality, reliability and lifetime (incl. sensors & actuators, ECS HW/SW, monitoring systems,...);
4) manufacturing and supply of energy relevant components, modules and systems;
5) the game change to renewable energy sources and decentralized networks, including intermediate storage;
6) energy supply infrastructure for e-mobility, digital live and industry 4.0;
7) “plug and play integration” of ECS into self-organized grids and multi-modal systems;
8) safety and security issues of self-organized grids and multi-modal systems;
9) optimization of applications and exploitation of achieved technology advances in all areas where electrical energy is consumed.
10) ECS for storage solutions.

8.2.2. Societal benefits

The ECS for energy (incl. components, modules, CPS, service solutions), which support the EU and national energy targets, will have a huge impact on the job generation and education if based on the complete supply chain and fully developed in Europe. The key will be the capability to maintain complete systems understanding and competence for small-scale solutions up to balanced energy supply solutions for regions. It is mandatory to have plug-and-play components that are enabled

by broad research contributions from SMEs and service providers including EU champions in the energy domain. Thanks to the expected wider proliferation of energy storage devices in the smart city context, new distributed forms of energy storages will become available, to be exploited by smart control systems.

Societal benefits include access to knowledge, development of modern lifestyle and availability of energy all the time everywhere – with a minimum of wasted energy and a minimum of greenhouse gas emissions. Applications having a huge energy demand and therefore a large saving potential are in the areas of High Performance Data centres serving the mobile connected world, the implementation of Smart Cities and the future implementation of e-mobility with widely distributed charging stations, demanding a higher density of energy distribution points with – as a key point - local intermediate storage systems.

Smart grid delivers smart energy from suppliers to consumers using digital technology to control appliances at consumer's homes to save energy, reduce cost and increase reliability and transparency.

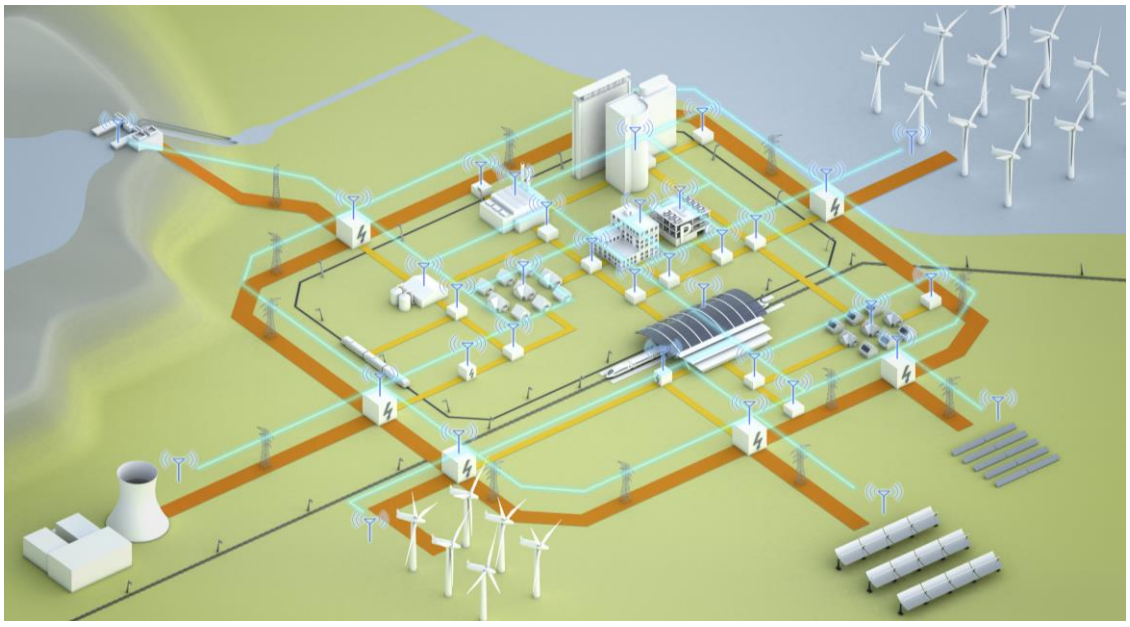


Figure 16 - Smart Energy landscape – from centralized to distributed (PV, wind, biogas, ...) generation and conversion, consisting of High/Medium Voltage grid (orange), Low Voltage grid (yellow) including Communication Network (aquamarine) linking producers and consumers down to regional and community level (source ECSEL MASP 201627).

[27] http://www.ecsel.eu/web/downloads/documents/ecsel_gb_2015_46_-_masp_2016.pdf

Figure 17 - The Prosumer concept. The Power transmission lines turn from one-way to two-way ones

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

8.3. Major Challenges

8.3.1. SWOT analysis

The table below presents a SWOT analysis on the current European position in Energy. These points are addressed in the paragraphs discussing about the individual major challenges and expected results.

	Positive factors	Negative factors
Internal factors to the EU ECS industry[28]	**Strengths:** Europe has a leading position. Four European based power semiconductor suppliers amongst the top 12 having together a market share of over 24% in 2014. Three power modules suppliers in the top ten with a market share of over 33%. The overall share of European suppliers is increasing in this growing market underlining their competitiveness	**Weaknesses:** Ability to follow very fast changing environment Speed of introduction of regulations "100 years old" established infrastructure to be converted into a highly flexible and dynamic energy supply infrastructure
External factors to the EU ECS industry	**Opportunities:** Affordable energy conversion efficiencies (93% - 99% or more) allowing better use of renewable energy resources, exploiting new materials, new device architectures, innovative new circuit topologies, architectures and algorithms lowering the total system cost. New infrastructure for EV charging is required Energy highway through Europe has to be implemented Emissionless Cities require electric approaches. Decentralized smart Storage Distributed DC network & Grid technology Efficient management of data and data storage.	**Threats:** Availability of renewable energies in sufficient amount Oversupply and peak supply challenges for variable energy sources Availability of batteries and their installation Distribution grid – complexity of current setup and missing acceptance of new HV and DC grid connection Missing investments into DC voltage infrastructure since very long lasting decisions have to be taken in a fast changing environment Environmental changes Fragmented legislations

Figure 18 – SWOT analysis of the position of the European ECS industry for energy

[28] EU industry here means the full Large Industry + SME + RTO + University eco-system

8.3.2. Major Challenge 1: Ensuring sustainable power generation and energy conversion

8.3.2.1. VISION

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

8.3.2.2. SCOPE AND AMBITION

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

8.3.2.3. COMPETITIVE SITUATION AND GAME CHANGERS

The need for energy is a fact in the modern society. The question is how to provide the energy in a resource efficient way and at a cost accepted by the society. Nano-electronics is playing an important role in the generation of renewable energies. Highly efficient conversion leads to fewer investments and therefore lower cost for the renewable energies. CAPEX and OPEX reduction per generated power unit is the only way to compete with traditional energy sources.

In terms of power semiconductors, which are the fuel for energy efficient systems, Europe has a leading position with four European based suppliers amongst the top 12 having together a market share of over 24% in 2014 for power semiconductors and three in the top ten with a market share of over 33% for power modules. Overall, the share of European suppliers is increasing in this growing market underlining their competitiveness.

8.3.2.4. HIGH PRIORITY R&D&I AREAS

- Affordable energy conversion efficiencies of 93% to 99% or more allowing better use of renewable energy resources, exploiting new materials, new devices architectures, innovative new circuit topologies, architectures and algorithms lowering the total system cost.
- Enhanced device and system lifetime and reliability with effective thermal management ensuring life expectancy for renewable energy systems to be 20 to 30 years.
- Developing semiconductors-based solar energy technologies including photovoltaic technologies and integrating them with solid-state lighting applications.

- Reduced physical size and weight of individual transformer stations with equivalent power ratings by the development of solid-state transformers. These actuators will provide new functions for the operation of power systems and avoid infrastructure extensions caused by increasing share of distributed generation.
- Innovative devices exploiting new materials to dramatically increase their power density capabilities to be used in efficient converters, supported by passive elements, new interconnect technologies and packaging techniques to achieve further miniaturization and further reduce losses.
- New nanomaterials, devices and systems for improving energy efficiency of the growing worldwide renewable energy technologies, such as photovoltaic, wind and water.
- System EMI research to cope with higher switching frequencies and further miniaturization.
- System reliability enhancement with focus on thermo-mechanical and thermo-electro-mechanical reliability.
- Resilient control strategies, and self-healing systems technologies that enable better use of renewable energy sources, their real-time monitoring, performance prediction, proactive coordination and integration with smart urban systems.
- Smart sensor networks able to measure all internal and external physical parameters that influence energy conversion efficiency and thus help to enable an efficient smart energy landscape. This also includes sensors that support intelligent predictive maintenance concepts resulting in reduced maintenance costs and increased lifetime for equipment and infrastructure.
- Self-powering systems for small IoT nodes have to be developed. The target is that local energy harvesting will substitute battery powered devices and eliminate the high demand of energy for the battery manufacturing and distribution logistics.

8.3.2.5. EXPECTED ACHIEVEMENTS

It can be expected that new highly efficient technologies (e.g. wide band gap materials, disruptive innovations based on new processing approaches and architectures) are introduced and new competitive solutions lead to a further growth of market share in the supply of power semiconductors. On the system level, it is expected that European suppliers are established in the field of resilient control strategies that enable better use of renewable energy sources, their real-time monitoring, performance prediction, proactive coordination and integration with smart urban systems. For the energy supply of the IoT nodes, harvesters and intermediate storages have to be developed to substitute and minimize batteries.

8.3.3. Major Challenge 2: Achieving efficient community energy management

8.3.3.1. VISION

The decentralization of energy sources, opportunities with networked systems, limitations in peak electricity supply, oversupply times, new demand for electric energy supply for the

urban mobility and the introduction of storage systems will lead to new challenges in energy management and distribution for communities and cities.

To illustrate the change and challenges in the distribution of energy a PV and wind energy example is given: Over the last 6 years, electricity demand in the UCTE countries grids have slowly decreased, from 2 600 to 2 500 TWh. In the same time period, wind and solar PV production increased by 79% and 338% respectively, reaching 226 TWh and 94 TWh in 2015. This development has led to variable renewable energy (VRE) accounting for 12.8% of total electricity production in 2015. The share of VRE for 2015 and projected for 2021 is shown in the following figure of selected **UCTE countries**29:

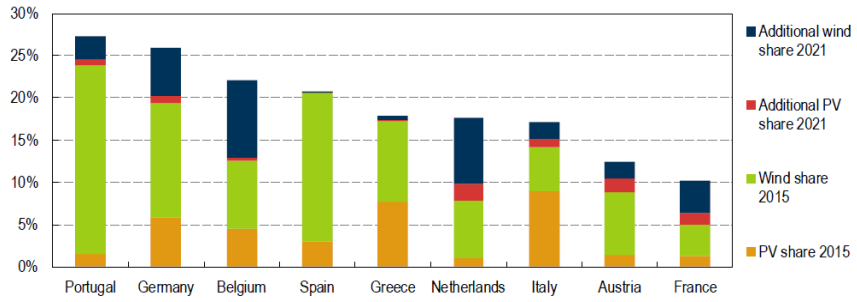


Figure 19 - Share of VRE generation in 2015 and 2021 for selected UCTE countries. Source: Adapted from IEA (2016a), Medium Term Renewable Energy Market Report

8.3.3.2. SCOPE AND AMBITION

The scope and ambition is, through the technologies supported, to reach the highest efficiency and most economic energy supply and management solutions for the communities and smart cities, including the distribution of energy to them.

8.3.3.3. COMPETITIVE SITUATION AND GAME CHANGERS

Advanced control and monitoring systems are already deployed at the transmission network level (high DC voltage). Broad inclusion of small and medium size renewable energy sources into the grid and their coordination requires adoption of control and monitoring systems at the medium voltage levels as well. In the medium voltage grids where small and medium size energy sources represent a significant part of installed energy production potential, real-time monitoring of energy flows is needed to enable demand/response management (DRM).

8.3.3.4. HIGH PRIORITY R&D&I AREAS

- Smart Grid applications that exploit demand/response technology in a robust and secure way, negotiating the trade-off between different levels of urgency in energy need with

[29] Large Scale Electricity Interconnection 2016, IEA

a varying price of that energy at any given time and accommodating variable renewable electricity;
- Self-organizing grids and multi-modal energy systems;
- Improved grid visibility through advanced grid monitoring, including medium and low voltage levels;
- A highly resilient power grid through the introduction of proactive control algorithms (that go beyond demand/response), significantly improving the grid's self-healing and self-protection capabilities;
- Full implementation of Smart Grid technologies, resulting in the massive deployment of the necessary control options for the complete realization of the Agile Fractal Grid also including smart agriculture (e.g. greenhouse energy efficiency);
- Smart E-Mobility grid for optimized charging, storage and distribution of electric power for light, medium and heavy vehicle transportation;
- Technological solutions for efficient and smart buildings (indoor) and outdoor subsystems including heating, ventilation, air conditioning and lighting, as well as traffic access, to achieve optimal energy-efficient performance, connectivity and adaptive intelligent management while ensuring scalability and security;
- Fog / cloud computing to offer sufficient and cost-effective processing power and to ease maintenance and update of control software - edge computing to support low latency applications, such as real-time grid control.

8.3.3.5. Expected achievements

Medium voltage level management (DRM) helps to adjust consumption to the production (presently the production is adjusted to match the consumption), promotes dynamic pricing tariffs that are needed to increase market share of small energy producers and at the same time enables the reduction of energy losses by better matching of production and consumption. Improved energy management at the MV level enables risk-free integration of additional renewable energy sources into the grid without any negative impacts on grid stability of the MV an LV micro-grids. Real-time monitoring at the MV enables the deployment of self-healing MV grid strategies.

The impact of electrification will help e-mobility trough a migration versus demanding technologies:

- Trend towards decentralization of energy & energy storage;
- New applications for energy distribution: Mandatory to sell EV;
- Fast charging >20kW: High Electronic content / Moving to SiC Based Modules.

8.3.4. Major Challenge 3: Reducing energy consumption

8.3.4.1. VISION

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

8.3.4.2. SCOPE AND AMBITION

Three prominent and fast growing areas are addressed:

- the reduction of power consumption by the electronic components and systems themselves;
- the systems built upon them; and
- the application level in several areas.

Electronic components examples:

- One of the most challenging issues in High-Performance Computing is *energy consumption*. It is a well-known fact that the energy consumption of HPC data centres will grow by a significant factor in the next four to five years. Hence the costs of associated cooling infrastructures (with 50%-70% of the overall power dedicated to the cooling task of the current generation data centres) already exceed the costs of the HPC systems themselves. Therefore reduction of energy consumption is becoming mandatory. Otherwise the consumption of exaflop systems will reach up to the 100 mega-watt ranges.
- The demand for mobile electronic equipment: the scaling is tremendous since billions of mobile electronic devices are deployed and connected to the grid each year. Even low percentage improvements have a high impact on energy consumption.
- The demands for communication networks: increasing data volumes (1000 fold increase in mobile data volume), always-on availability, instant messaging – they all demand a permanently active infrastructure avoiding any inefficient operation. In order to avoid explosion of energy consumption of the communication networks, energy per transmitted data unit needs to be cut drastically. In the 5G development, the target is set to limit the energy per transmitted bit to $1/10^{th}$ of today's level. To reach the target several measures needs be applied, e.g., electronic beam-forming techniques, efficient communication algorithms and highest efficiency components.

System configurations:

The energy efficiency of the system is achieved by using sensors, actuators, drives, controls and innovative components where the loss of energy can be reduced by innovative or even destructive approaches. The ambition is to reach a wider implementation of adaptive and controlled systems to meet the needs through monitoring and the ability to reduce energy losses. For example, intelligent building management systems can guarantee minimal energy use for heating and lighting (also providing safety and security).

Application level:

MEPS minimum energy performance standards 30.

Under the EU Ecodesign Directive, the European Commission sets MEPS for 23 categories of products sold in Europe. The Commission is currently considering revising or developing standards for the following product groups: air heating products, cooling products and process chillers, enterprise servers and data storage products, machine tools and welding equipment, smart appliances, taps and showers, lighting products, household

[30] ENERGY EFFICIENCY Market Report 2016 – International Energy Agency

refrigeration, household washing machines and dishwashers, computers, standby power consumption, water heaters, pumps and vacuum cleaners. Further, under the Energy Performance of Building Directive, there is a continuous tightening of national minimum energy performance requirements in line with the cost-optimal methodology.

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

8.3.4.3. COMPETITIVE SITUATION AND GAME CHANGERS

Having the whole value chain represented and being in world-wide leading positions, Europe has a rather good chance to build up a healthy "green industry" around tools and goods to reduce energy consumption. European companies have acknowledged strengths in power electronics and in nearly all of its applications. Market studies show leading positions of Europe in the field of power electronics and advanced LED lighting and even dominance in power semiconductor modules for renewable energies. Activities inspired, founded and led by European stakeholders such as the GreenTouch® initiative or a number of ETSI and ITU standardisation initiatives and focus groups exert worldwide influence. By resorting to latest micro-/nano-electronic technologies and most advanced system concepts, European companies defined and set new standards and raised the bars in performance and energy efficiency. Also the related R&D is very active in all of those domains.

8.3.4.4. HIGH PRIORITY R&D&I AREAS

- Intelligent drive control: technology, components and miniaturized (sub) systems, new system architectures and circuit designs, innovative module, interconnect and assembly techniques addressing the challenges at system, sub-system and device level for efficiently controlled engines and electrical actuation in industrial applications
- Technologies and control systems to improve energy performance of lighting system;
- Highly efficient and controlled power trains for e-mobility and transportation;
- Efficient (in-situ) power supplies and power management solutions supported by efficient voltage conversion and ultra-low power standby, based on new system architectures, innovative circuit and packaging concepts, specific power components for lighting and industrial equipment serving portable computers and mobile phones, and standby switches for TVs, recorders and computers. Power management solutions in industrial, municipal and private facilities;
- Low weight/low power electronics, with advanced thermal management solutions, based on novel materials and innovative devices particularly benefiting, among other areas, medical applications, where improved energy management is one of the keys to cost-effective solutions (for example, medical imaging equipment);

- Immediate issue to be solved on the way towards exascale computing is power consumption: The root cause of this impending crisis is that the needs for ever increasing performances require larger amount of devices (and associated memory) while the chip power efficiency is no longer improving at previous rates. Therefore, improvements in system architecture (e.g. clock switching, etc.) and computing technologies (i.e. usage of low-power processors and accelerators like GPU, FPGA, etc.) are mandatory to progress further;
- Related issue of heat dissipation in computing system requires sophisticated air or liquid cooling units (e.g. chilled water doors, refrigerated racks, heat exchangers, etc.) further adding to the costs;
- Together with computing technologies (CPU, GPU, DSP, etc.) interconnect technologies add their own energy consumption, thus requiring further efforts to optimize routing strategies and switching policies in order to minimize the traffic. Usage of 3D nano-electronics based integrated devices and photonics can be envisioned for such improvement;
- Energy efficient sensor networks, including hardware and software application layers;
- Optimal parallelization of traditional sequential algorithms and efficient mapping on parallel and heterogeneous architectures will not only provide necessary performance but help to reduce energy consumption;
- Energy efficient communication networks with highest efficient ECS, beam forming and embedded algorithms.
- Efficient adaptive power management for 5G wireless network.

8.3.4.5. EXPECTED ACHIEVEMENTS

The expected achievements are directly linked to the R&D priorities. Worth of highlighting is that in several applications a huge price pressure, neglecting the benefits via reduced operational costs over the lifetime, asks for severe achievements in cost reduction of technologies. The achievement of exascale high-performance computing capability by 2020 requires a reduction by at least a factor of 5 of the current consumption in order to stay in the domain of technical and economic feasibility.

Following is a list of potential implementations to support the objective of energy consumption reduction: added increased share of intelligent drive control, electrical actuators for robotics, enterprise servers and data storage products, lighting products, household refrigeration, washing machines and dishwashers, computers, standby power consumption overall, water heaters, pumps and vacuum cleaners. Further potential is seen in highly efficient Industry 4.0 improvements based on sensor data and new control for actuators.

8.4. Make it happen

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

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

8.5. Timeframes

Energy	Short term	Medium term	Long term
Overall – Embedded in EU strategy	EU targets for 2020 supported (20/20/20) - greenhouse gas levels by 20% reduced - share of renewable to 20% increased. - reduce energy con-sumption by 20% Projection regarding the targets in 2020: 24/21/17	ECS for recovery of the not matched targets in 2020 and preparation for 2030 targets Supply by European manufacturing of ECS secured	EU targets for 2030 supported by ECS from European suppliers: share of renewable energy in the electricity sector would increase from 21% today to at least 45% in 2030 (1)

Figure 20 - Energy summary roadmap

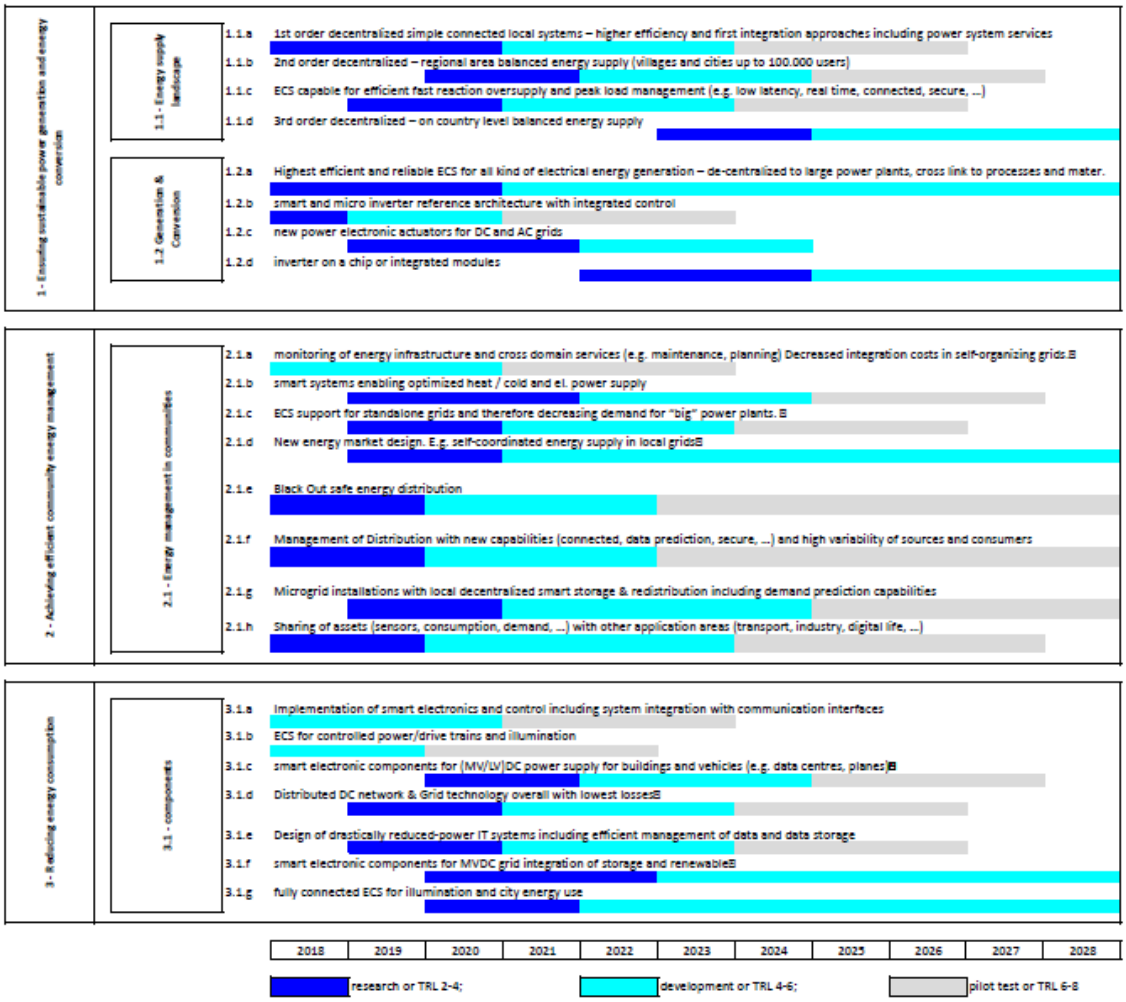


Figure 21 - Energy roadmap

8.6. Synergies with other themes

Synergies can be found with all other chapters in terms of energy efficiency that enables new approaches in automotive, society or production.

The bases are the technologies, both power semiconductors and efficient µC, and all actuators such as sensors and actuators for energy-efficient measurements.On the other hand, the physical and functional integration technologies for the realization of the systems are built with the components in accordance with the criteria of durability and reliability.

Security aspects related to Energy are considered in chapters Transport and Smart Mobility, Connectivity and Interoperability, Dependability and Trustability, Computing & Storage.

With reference to the Transport and Smart Mobility chapter, as the new concepts of automotive powertrain will be battery powered vehicles, fuel cell vehicles and hybrid engines, there is a need for new technologies with greater efficiency and robustness, so there is a strong connection with high priority R & D & I areas defined in Chapter Energy.

9. Digital Industry

9.1. Executive Summary

Digital Industry will require new applications and methods to make current factories work at the maximum flexibility & efficiency and to optimize production level. As there will be fewer workers, they will have to handle more information. The only way to support that information flow is to use new innovations and integrate them in the normal work flow. This means that the user should have access to information as he/she needs it. This kind of easy access still requires security and a lot of back-end server capacity to process information ready to be used. An optimal system will set itself up according to the designed and installed system. This means we should have self-organizing intelligence at the factory level.

Disruption can happen as wireless sensors and new field connectivity solutions are needed with industrial internet. Cloud based network and integration will change value chain. One challenge is to use this kind of network in a fast and dynamic way.

9.2. Relevance

9.2.1. Competitive Value

Sigitalisation of industries has already advanced to a high international level, and European factories, as well as, factories globally that are built by European companies have high automation and sigitalisation level. Many of the leading end-user companies of the domain are European based, and we also have a number of significant system and machine building, engineering and contracting companies in Europe who have drawn their competitive edges from automation and digitalisation. The business environment has also been changing, i.e., we tend to specialize on new or niche end products, production is becoming more demand-driven or agile, production is more and more geographically distributed, outsourcing of auxiliary business functions such as condition monitoring and maintenance, is gaining popularity leading to highly networked businesses. There are many opportunities for energy, waste, material, recycling optimization, etc., over the value chains and across company boundaries. Such advantages are only realized by having a significantly more extensive digitalisation in place.

Digitalisation as such is again changing and advancing. Internet has become a backbone for many kinds of global and local, near process and enterprise level, open and confidential - process and business management functions. Internet offers, in principle, integration, interoperability, remote operations that are offered today as so-called cloud services. Data, or big data, has become an asset for many kinds of situational awareness, predictive

analytics, deep learning, wide optimization and in general new artificial intelligence applications. Modelling and simulation, virtualization offers versatile opportunities for both factory design and operative factory management. European industrial policies now emphasize to build a digital single market for European industries. To achieve this, industrial applications need much more capable internet than what traditional internet alone can offer. On top if internet, we need so-called industrial internet whose functionality and form is now developing under the title Industrie4.0. Industrie4.0 is expected to contain all the elements that are needed to realize the heavily software and automation managed global, distributed and flexible businesses, across value chains, across company and geographical borders, from process to business function levels. New digitalisation is emphasized as we are now entering into an era of novel products calling for new processes, new business models, etc.

As in all digitalisation, cybersecurity becomes a necessity to be solved. New generation digitalisation needs secure exchange of data. If not solved properly, cybersecurity issues may become show stoppers. Networked businesses also bring along hesitations of trust: how can companies in an open-like digital environment trust each other in a constructive way. The whole world is now on fingertips for everyone creating the needs of new business culture, contract bases, legislations, market places, business models, i.e., new conditions for growth and success.

Sustainable production must be optimized and accurate. It must be energy efficient and use raw materials in effective and even clever way. Raw materials can and must be maximally reused or circulated. The amount of waste or discharges shall be minimized. Industrial Internet solutions can monitor and report these, and also give basis for many kinds of decision-making, both operative and design or building time.

As, e.g., Amazon sells a lot of consumer goods, this kind of trading needs far more efficient logistics, which may have tremendous effects to production at the same time. The whole value chain is coming more end-customer driven, agile and faster. 3D printing could be one solution for faster delivery and lighter logistics.

Consumer electronics for AR/VR/MR are emerging from game industry and very attractive also to industrial use. These devices are becoming technically more viable, cheaper and providing new possibilities for users at the factories. At the same time cognitive services using speech interfaces are becoming ”intelligent” or applicable. Several such devices like Alexa, Echo and Homekit are about to become available. In the same way, there are AR/VR/MR kits from the game industry with reasonable pricing and with good frameworks. They will enable fast proto-typing. Google Glass 2.0 was just released for enterprise use and it shows the current trend.

There should be industrial grade devices with safety helmet and they should meet other environmental requirements. Machine learning, AI and chatbots are providing new effective assistants to workers on the field. As digital twin and simulation-based models are built, they can provide effective ways to get real benefits.

Actual chip design that will support this is going to provide deep neural network acceleration inside CPU. Intel has developed HPU (Holographic Processing Unit) and now the next version will contain deep neural network (DNN). In the same way NVIDIA is providing new graphics processing units (GPUs) for cloud machine learning.

Wireless sensors and Ethernet based field connectivity will change the cost of measurements. Different kind of low cost versatile chips will differentiate and move connectivity towards Industrial Internet. This is one clear value that EU should take care.

9.2.2. Societal benefits

Digital Industry should be used for existing already build production facilities. There are thousands of systems running that could be more effective and reduce maintenance costs and shorten downtimes. Hardest part of the work is to build it to be dynamic and self-learning. This way it will be cost efficient to setup and maintain.

Actual value chain will come from the existing installations as there are not so big market for the new factories. Even the latest new production units will be strong references how IoT will affect to Digital Industry. As the new, fast & secure communication protocols will provide easy connectivity and interoperability across the systems it will enable all the integration possibilities. Easy access in secure internal network will provide all existing information to user who is at the plant. But more interesting features could be provided with cloud or edge based intelligence. This requires new hardware to be added to plant and more processing power that can handle large amounts of data.

As to build these kinds of systems to top of existing installations there should be reasonable ways to integrate existing legacy systems at the design & communication level. There are existing protocols and architectures to implement this, but it should be more effective. New gateways and frameworks should be experimented and then productized. This way we can build new Industry 4.0 based way that will make it possible to integrate new services.

New services should be attractive to customers so it will create value. A service can provide maintenance information predictive or help in trouble shooting. Value comes to end customer from the savings in the maintenance and less downtimes / more production. In the same way, a service can optimize energy or material usage so the production is more profitable.

Knowledge from machine learning and artificial intelligence can be used by service personnel. Users are more valuable and they must learn little bit more about analysis. The use of intelligent services will come more practical and usable for engineers.

Carbon footprint can be minimalized with new Industrial Internet based solutions. Service people and other personnel does not have to travel in many cases. New solutions can provide dashboards and remote support though connections over Internet. Experts can be working from home instead of flying in airplane (this can be even 70% of time).

Servitization, business models based on machine data

Digital infrastructure and micro services will change business models more on towards selling added value as a servitization. Investment project creates network and connections between vendors and providers that end user (mill or factory) wants to use. For example, maintenance or some other service and condition monitoring needs to get real data from the factory & devices. This kind of value chain contains heterogenous systems that should be one channel for end customer. One dashboard view with background systems will integrate perhaps to whole factory information and the value of the data in key element for the new business. Value chain is integration of multiple sources to one single view. next steps are to create actual event notification between the systems like SAP / ERP etc.

In modern machine vendor to end-customer B2B relationships, recent and ongoing R&D or industrial pilots are aiming at delivering many kinds of after-sales services to the end-customers. Most typically, such services include condition monitoring, operations support, spare parts and maintenance services, help desks, troubleshooting, and operator guidance, performance reporting, as well as and increasing in demand, advanced big data analytics and prognostics-based decision support. The markets for this service is still in its infancy. Many end-customers are still hesitant to outsource their condition monitoring business processes but, at the same time, significant joint benefits have been demonstrated by organizing such business processes as commercial services and allowing the end-users to pay more attention to furthering their core businesses.

Industrial services represent often 50%, or beyond, of the industrial business volume, and the share is steadily growing. The share of services is in general higher in the so-called high-income countries than in low-income countries. The importance of service business in the future is evident as the service business enables revenue flow also after the traditional product sales and, more importantly, the service business is typically many times more profitable than the product sales itself. The service business markets is becoming more and more challenging, while the high-income countries are focusing on high-skilled pre-production and after sales life-cycle stages. Fortunately, in the global service business market, Europe can differentiate by using its strengths: highly skilled workforce, deep technology knowledge and proven ICT capabilities, but the success needs new innovations and industry level changes.

9.3. Major Challenges

9.3.1. Major Challenge 1: Developing Digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles

A **digital twin** is a dynamic digital representation of an industrial asset that enables companies to better understand and predict the performance of their machines and find new revenue streams, and change the way their business operates. Nowadays, machine

intelligence and connectivity to the cloud allows us an unprecedented potential for large-scale implementation of digital twin technology for companies in a variety of industries. A physical asset can have a virtual copy running in the cloud that gets richer with every second of operational data.

Simulation capability is currently a key complement to European machine tool industry expertise in order to increase competitiveness. According to Industry 4.0, modelling plays a key role in managing the increasing complexity of technological systems. A holistic engineering approach is required to span the different technical disciplines and prove an end-to-end engineering across the entire value chain.

The manufacturing industry can take advantage of digital twin and simulations from different perspectives. Focusing on **virtual commissioning** with the digital twin, manufacturers and their suppliers can face in an efficient way the pressures of competition: changing customer demands, ever shorter product lifecycles, increasing number of product variants, reduced product launch times, and increasing pressure in terms of earnings. At the same time, and to address these pressures, ever more flexible production machines and production systems are being introduced, with sophisticated tooling, mechanized automation, robots, transfer lines and safety equipment.

Commissioning is the phase when deliveries from mechanical, electrical and controls engineering come together for the first time to form the production machine or system. Until now, such integration was only possible on the shop floor, which meant that every realized change or rework at that stage generated delays, increased costs, threatened loss of reputation, and potentially reduced market share, undoubtedly if such changes adversely affected machine delivery or production launch. Virtual Commissioning allows engineers to connect the Digital Twin to the PLC to test, refine and optimize mechanical, electrical and logical designs, and the integration between them, well before hardware is assembled on the shop floor, without the need to delay delivery or stop production.

Virtual Commissioning provides:

- A common virtual space for mechanical, electrical, controls and systems engineers to collaborate and develop simultaneously, rather than serially, at an early stage.
- An environment to perform early testing of mechanical behavior as driven by controls, early testing of control logic through observation of machine or system reaction to PLC output, and PLC reaction to machine or system input.
- In-depth simulation of the entire production plant with all its components, allowing ramp up or reconfiguration with minimal production stoppages.
- Shifting of commissioning off the production floor, reducing on-site personnel during the final commissioning phase from several weeks to a few days, cutting costs significantly.
- A realistic validation of a machine or system allowing for identification and resolution of errors, as well as optimization of the logic programmed into the PLC, by visualizing such things as improper material flow or an incorrect sequence of events.

Virtual commissioning scenarios can be comprised of robotic assembly systems (assembly lines, material handling systems, and machines with integrated robotics), conveyance-centric material flow systems (conveyors and devices, whereby the devices are attached to or perform in concert with the conveyors) and machine tools (PLC and CNC controls where physics behavior of parts, such as gravity, force, torque, and load profiles used for sizing drives gain importance).

Moreover, in a complementary approach, a digital twin can be focused in machining process simulation. Machining process performance is related to the combination of the different phenomena (machine tool kinematic and dynamic behavior, machining process, tool path, workpiece dynamics, etc.), and it is necessary to integrate the most important effects in a common simulation environment in which the machine tool, the process and other aspects are simultaneously analyzed. A holistic approach based on improved simulation models of energy efficiency or maintenance optimization can provide more accurate estimations. It is also important to remark that machine monitoring data combined by the model-based estimations will allow an improved performance of the manufacturing process by controlling component degradation and optimize maintenance actions, increase energy efficiency, modify process parameters to increase efficiency or even smoothen it to protect a degraded component until the next planned maintenance stop, etc

All indications seem to predict we are on the cusp of a digital twin technology explosion enhance the necessary collaboration between machine tool builders and part manufacturers in order to improve the productivity of the manufacturing processes.

Besides virtual commissioning, modelling and simulation serves, to wider extents, many kinds of digitalisation challenges:

- understanding, explaining, and visualization of physical or real-world phenomena underlying products, production, businesses, markets, etc.
- helping designers to perform their core tasks, i.e., studying alternative designs, optimizing solutions, ascertaining safety, providing a test-bench for automation and IoT solutions.
- the effects of changes can be safely and more comprehensively tried out in virtual domain than with real plants, equipment or even mock-ups.
- simulators offer versatile environments for user or operator training
- it is evident that former CAD driven digitalisation moves focus towards simulation-based design.

Simulators may be used online and parallel with its real counterpart to predict future behavior and performance, to give early warnings, to outline alternative scenarios for decision-making, etc. Such tracking simulators are, in spite of long research, at their infancy, at least in industrial use.

9.3.1.1. SCOPE AND AMBITION

Digital twin contains simulation, modelling, but also documentation and design are “alive” as digital. They are constantly updated as there are changes in production and/or process. There is need to have digital platforms that will enable infrastructure that can be used to automate needed background processes.

9.3.1.2. COMPETITIVE SITUATION AND GAME CHANGERS

Siemens has adopted the term “digital twin”; though the term has been in popular use generally and earlier, too. Siemens is providing Comos platform that enables application life-cycle management. Mindsphere brings IoT platform as a commercial solution.

GE has similar kind of products and initiatives.

There are multiple this kind of digital platform aiming to digital single market. Commercial providers are dominating market as research solutions are only practical examples and proof-of-concept studies.

9.3.1.3. HIGH PRIORITY R&D&I AREAS

- Virtual commissioning
- Interoperability is one major challenge. Applications cannot yet be used between platforms. Heterogeneous systems are and remain a challenge.
- having all relevant engineering disciplines (processes, assembly, electronics and electrical, information systems, etc.) evolving together and properly connected over the life-cycle phases. Multisimulation.
- Tracking mode simulation. Model adaption based on measurements.
- Generating simulators automatically from other design documentation, measurements, etc.
- Simulator-based design.

9.3.1.4. EXPECTED ACHIEVEMENTS

In ideal world interoperability works on communication level, but in application level there are ontological and semantic challenges. There is possibility to create standard to define applications and digital twins that could communicate together.

9.3.2. Major Challenge 2: Implementing AI and machine learning, to detect anomalies or similarities and to optimize parameters

There are several machine learning systems provided by major internet players like Google, Microsoft Azure and IBM Watson. These are using different kind of implementations from the deep learning or other algorithms. Deep learning needs usually a large amount of training data to be accurate. There is need for time series data handling to detect similarity or anomaly with easy setup. This is one basic principle that is required to get successful

implementation to industry. As there are not so many data scientists for every company & domain, solution should be studied to be possible to use with normal automation engineering person.

Even we have large libraries implemented with different programming languages it is not enough as an engineer with PLC / DCS understanding cannot use those. This will require software or framework that can be configured and connected easily to system. The existing runtime systems are most probably not fast enough or not even capable to run algorithms fast enough in certain cases. Again, this will require own edge computing device (perhaps with GPU) to run analysis to provide result in reasonable time.

Another interesting part is cognitive services. As Alexa, SIRI and Cortana will understand speech and run actions or use background services they are providing new natural language understanding (NLU). One problem with these services is how to integrate them to production unit without access to Internet. It will require some security and DMZ setup to use it in safe way. Or implementation could be own hybrid cloud solution. Anyway, this with the new AR/MR application can be a real game changer for the user interfaces. Maintenance people can talk & walk and get instant information from the devices & systems nearby them.

9.3.2.1. SCOPE AND AMBITION

Scope is on how to use and get applications for domain users. Intelligent services will provide knowledge and information to user. It should be normal and transparent. Digital industry can be used by normal engineer. He/she does not have to be a programmer or data scientist.

Since industry has been digital in many way for decades and in growing proportions, it has also developed its own system engineering concepts, tools, languages, platforms and standards. Examples include PLCs, DCSs, alarm systems, CAD. Today, this technology basis is drastically expanding to the variety of concepts and technologies, grouped conveniently under the title cyber-physical system or industrial internet, etc. Machine learning, big data, deep learning and artificial intelligence are significant examples. What is still striking is that bringing these technologies into industry tend to remain research initiatives, pilot experiments, proofs of concepts, or else, which makes real applications tailored, brittle, non-transparent, and difficult to understand and manage, in other works expensive or untrustworthy or at least low-level. The so-to-say yesterday's technologies are engineered in place which is very beneficial and practical, not experimented or studied as science. Therefore, we clearly see the need for strong reference architectures, design languages, application generators, design automation, and respective standardization.

9.3.2.2. COMPETITIVE SITUATION AND GAME CHANGERS

Main players are coming from the US. They are dominating cloud based solutions.

Local edge based intelligence is one opportunity.

The biggest AI and machine learning acquisitions will continue as Facebook bought Ozlo, Google acquires Kaggle and Halli Labs, Google acquires AIMatter, Microsoft acquires Maluuba, Apple acquires Realface, Apple acquires Lattice, Amazon acquires Harvest.ai and Spotify acquires Niland.

	Positive factors	**Negative factors**
Internal factors to the EU ECS industry[31]	**Strengths:** Presence of strong industrial players in EU (Bosch, Schneider, Siemens, ABB, Beckhoff etc.) Much creativity in EU Great design capabilities in EU …	**Weaknesses:** Fragmented market across countries Limited start-up / VC culture Few social media companies in EU Personalised cloud providers from US …
External factors to the EU ECS industry	**Opportunities:** Ubiquitous availability of smart phones Low-cost availability of accurate sensors Advent of IoT, 5G and AI/Deep Learning Advent of VR, AR, BCI, Robotics, … Advent of self-parking car, … Disruption: collaborative business models	**Threats:** Big players: Google, AWS, IBM, MS Providing platforms & Machine learning **…**

Figure 22 - SWOT analysis of Digital Industry in Europe

- Collaboration between industry and research is one key activate to combine research & practical implementations.
- More advanced SOC for Edge computing (Intel & NVIDIA). Study level where this can be used.
- AR/VR/MR display technologies and camera use cases.
- Edge computing and chatbot / ML / AI use cases locally (inside factory). How to use cloud based intelligent services without Internet connection?
- ERP / MESH system API to get benefits from ML/AI results. Uncertain / KPI data from fleet. How to use this data in upper level?

9.3.2.3. EXPECTED ACHIEVEMENTS

- Capabilities to build digital industry with outperforming business.
- IoT chips for wireless & Ethernet based connectivity.
- Tools for engineers to use & get information & knowledge at all levels of personnel.

[31] EU industry here means the full Large Industry + SME + RTO + University eco-system

9.3.3. Major challenge 3: Generalizing conditions monitoring, to pre-warn before damages and to help on-line decision-making

Condition monitoring techniques can be applied to many types of industrial components and systems, however, often at an additional cost. To determine which level condition monitoring a machinery deserve a criticality index method can be utilized, categorizing machinery into Critical, Essential and General purpose, which takes into account factors such as downtime cost, spares proximity, redundancy, environmental impact and safety. Commonly, the wanted business value from condition monitoring comprises, e.g., higher availability of equipment and for production processes to be given the information to be able to plan and act proactively instead of reactively regarding maintenance, decrease cost and improved on-time delivery. Other business values that may be of interest as well are safety and optimal dimensioning/distribution of spare parts and maintenance staff. Thus, serious breakdowns and unplanned stops in production processes can be avoided to a larger extent using condition monitoring.

It is possible to combine quantitative approaches and methods (e.g. using machine learning, historical data/Big Data) with qualitative ditto in order to achieve a higher level of prediction accuracy and find more types of problems/issues. Regarding qualitative approaches and methods, they require a deeper understanding of the equipment or process and the application/area to be able to model the data and find relations based on sometimes more than 3-5 parameters that together may indicate issues. Further, (on-line) condition monitoring can be combined with other aspects in order to reveal additional issues/problems that otherwise would not have been indicated or discovered bas on condition monitoring alone. An example of such is continuous quality control that checks that firstly the input is within accepted ranges, secondly that the process parameters are OK, and thirdly that the output produced meet the expected requirements etc. Thus, if output problems are detected and all the others look OK, it is an indication that the equipment need maintenance or that the process needs to be adjusted.

To be able to achieve advanced condition monitoring, it is of importance that it is considered already during the design so that necessary sensors are included, data can be extracted at the rates needed, and it is possible to add additional sensors later on if needed. Otherwise, it will be hard to successfully and economically perform condition monitoring with the wanted business value as the outcome. In addition, using results from condition monitoring in re-designs or designs of new models/versions is encouraged as a lot of future problems can be avoided then (as well as achieving a higher reliability and potentially also a better maintainability if components or sub-systems which are error-prone are made easy to service and change parts within).

9.3.3.1. SCOPE AND AMBITION

- Continuous/online/real-time monitoring of industrial equipment.

- Fleet management, i.e., managing fleets of machinery, local and remote, benefitting from larger sets of similar components, etc., distributing experience, understanding common or similar characteristics and context specific characteristics.
- Modelling and integration of process and equipment
- Benefitting of or taking into account online condition in other applications of digital twin, i.e., MES, ERP, automation.
- Hybrid/linked simulation and analysis
- Flexibility and robustness of production process, enabled by monitoring and predictions
- Adopting of 5G to condition monitoring. May become a game changer

9.3.3.2. COMPETITIVE SITUATION AND GAME CHANGERS

The interest is very high and many realise the potential benefits that can be obtained with condition monitoring. On the 'use'-side, it is foreseen that those who use condition monitoring will be more competitive and profitable than those not using it. Further, on the provider-side, large companies show an increasing interest in condition monitoring systems and invest in the market. Larger provider-players include IBM, Schneider Electric, Microsoft, SKF and Bosch.

9.3.3.3. HIGH PRIORITY R&D&I AREAS

- Target KPIs and sustainability/environmental parameters
- Modelling and analytics tools
- Automatized modelling and analytics
- Multivariate- and multi- objective simulation and optimization
- Information management, data storage, digital preservation

9.3.3.4. EXPECTED ACHIEVEMENTS

Expected achievements are improved overall equipment efficiency and profitability through increased efficiency, flexibility and robustness of the production process. This is enabled by improved risk management using condition monitoring and predictive ability.

9.3.4. Major challenge 4: Developing digital platforms, application development frameworks that integrate sensors and systems

The role of IoT is becoming more prominent in enabling access to devices and machines, which in manufacturing systems, were hidden in well-designed silos. This evolution will allow IT to penetrate further the digitized manufacturing systems.

Industrial IoT applications are using the available data, business analytics, cloud services, enterprise mobility and many others to improve the industrial processes. The future IoT developments integrated into digital economy will address highly distributed IoT applications involving a high degree of distribution, and processing at the edge of the

network by using platforms that provide computing, storage, and networking services between edge devices and computing data centres.

Most companies now have difficult times justifying risky, expensive, and uncertain investments for smart manufacturing across company borders and factory levels. Changes in the structure, organization and culture of manufacturing occur slowly, which hinders technology integration.

There are a lot of initiatives around Digital Manufacturing and IoT Platforms, thanks to the many research and innovation actions at EU (C2Net, CREMA, FIWARE for Industry FITMAN, ARROWHEAD,…). However, those IoT driven platforms have not yet led to a successful and effective digitalisation of all the aspects and resources of manufacturing industry. This is mainly due to the heterogeneity of the IT supply side and of the heterogeneity of the domains to be addressed and transformed in the industry demand side.

Questions to be solved:

- Are the digital platforms meant for manufacturing business processes also suitable for real time excecution?
- Are performance and security issues solved?
- Are the proposed platforms reasonable for low tech SMEs?
- Can we define a Meta-Platform that acts as the translator between the different digital platforms?
- Can we define something similar to AUTOSAR, a standard way to communicate the different parts and platforms for the Intelligent Manufacturing ecosystem? Something to solve the interoperability problem? Each of the actors in an Intelligent Manufacturing ecosystem is using their own solution. Having a standard way to connect and have interoperability of those different digital platforms and different devices located at different levels of the factory will provide a competitive position to the European intelligent manufacturing ecosystem.

To solve this last question, The Industrial Internet Consortium (IIC) has defined the so-called Connectivity Framework. Connectivity refers to the infrastructure enabling communication between participants. Communication refers to the exchange of information between them. Without connectivity, there is no communication. Communication is the basis for interoperable systems, and to be meaningful, requires some context. The more context the connectivity infrastructure can maintain, the more meaningful communication. The Industrial Internet Connectivity Framework (IICF) defines the role of a connectivity framework as providing syntactic interoperability for communicating between disparate Industrial Internet of Things (IIoT) systems and components developed by different parties at different times. The IICF is a comprehensive resource for understanding connectivity considerations in IIoT. It builds on the foundation established by the Industrial Internet Reference Architecture and Industrial Internet Security Framework by explaining how connectivity fits within the business of industrial operations, and its foundational role in providing system and component interoperability when building IIoT systems. (http://www.iiconsortium.org/IICF.htm)

EFFRA: The diversity of approaches and implementations of digital manufacturing platforms, implies the need for the creation of Meta-Platforms to connect existing platforms, including abstraction layers for interface, protocol and data mapping to provide interoperability as a service. There is a need for holistic interoperability solutions spanning all communication channels and interfaces (M2M, HMI, machine to service) in the factories and supply chains.

In addition, new players are arriving from the IT sector:

- Hadoop
- Kafka
- Apache STORM
- IBM (Bluemix)
- Microsoft Azure
- Digital Enterprise Suite (SIEMENS), MindSphere (Siemens, open IoT operating system, turn data into knowledge, and knowledge into measured business success.)

How can they be considered in the intelligent manufacturing ecosystem? How can be integrated this tools in the digital platforms? How can be solved the IPR issues of the data and knowledge created by those tools?

9.3.4.1. SCOPE AND AMBITION

Study for meta-platform that can communicate with different platforms and integrate tools.

Managing complexities with AI-based design, self-configuration and with many kinds of autonomous adaptation. “How to connect intelligence!”

9.3.4.2. COMPETITIVE SITUATION AND GAME CHANGERS

There are actually several benchmarking studies about digital platforms, either underway or very recently completed. In the same way, companies are carrying out their own respective surveys. A general remark is that there are several digital platforms emerging, as research project outcomes, or actually as the result of several consecutive projects, both national and EU. Certain standardization is underway, most notably by Industrie4.0 (or RAMI) and IIC. Since the realms of respective applications are huge and, therefore, technologies as well, the standards actually consists of many standards that have been known and used for some time already; though there are needs to create new (sub)standards. The commercial digital platforms are also emerging, most notably Siemens MindSphere and GE Predix. At this writing, it is not clear which platform perhaps will win, or how the market positions will evolve. The situation very much resembles with the early stages of evolving operating systems of personal computers or mobile phones, or rather the early situation of industrial field-busses. As we well know, in some domains there have

been clear global winner, but for instance with filed-busses, several strong players seem to prevail. Due to the emergence of Industry4.0, rectification of initiatives is apparently taking place.

The research origin platforms may be more versatile than the current commercial offerings. At the end of the day, application industries may start choosing more and more commercially supported platforms but, as we have seen in recent history of ICT, open source platforms may keep their strong position.

Digital platforms are clearly becoming ever more state-of-the-art technologies, i.e., they are pushed somewhat in the background as we have operating systems of PC's today. The applications have been dominating engineering, in the past and in the future. As is clearly recognized in industry, applications in all life-cycle stages and on all system levels, both in digital and physical realms, are most valuable. The digital assets themselves are important, as well as, the connectivity of ever more elaborate and diverse applications.

9.3.4.3. HIGH PRIORITY R&D&I AREAS

Move focus on the industrial or engineering applications. It is important to win the global platform game on various application sectors (which are strong today) and in building effectively and on high level outperforming applications and systems, for the actual industrial and business needs.

Prepare for the era of 5G in communication technology, and especially its manufacturing and engineering dimension.

Solve the cyber-security problems. Only safe, secure, and trusted platforms survive in industry.

9.3.4.4. EXPECTED ACHIEVEMENTS

- Meta-platform could be used with other platforms, systems and tools.
- Easier, more comprehensive and tools supported integration of compound applications, on top of digital platforms.
- automated design features
- technologies to connect intelligence

9.4. Make it happen

Some initial ideas how to get involvement from industry to test research ideas. Participate and get on field experience.

Gartner / ARC studies about 50 billion IoT sensors => communication + storage => applications needed that will create actual information & value from the data.

Sensor price / unit + storage capacity + application execution = investment price

Existing standards can be used and there are a lot more applications based on standards.

Development cycle from chip provider to system designer and then to application can be shorter. E.q. actual framework & design flow is faster and creates value to stake-holders.

9.5. Timeframes

Timeframe below contains some pre-steps to get actual targets possible.

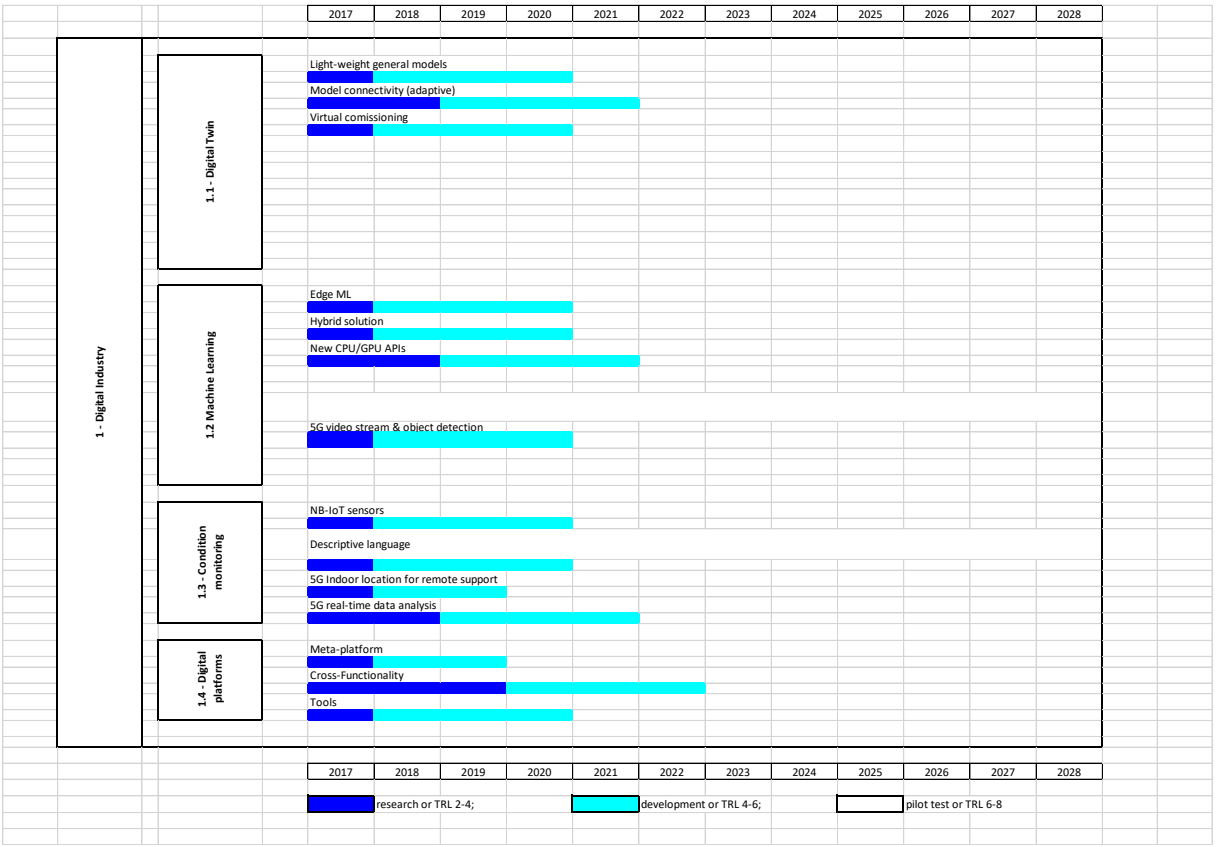


Figure 23 – Digital Industry roadmap

9.6. Synergies with other themes

Connectivity & interoperability is one key factor for Digital Industry that it will work.

- Connectivity: 5G in industry for
  - Fast communication
  - Indoor location
  - Interoperability
- Computing & storage:
  - Machine learning API for hybrid CPU&GPU
  - Storage for training data (wearable, low power & fast)

10. Digital Life

10.1. Executive Summary

Increasingly, digital services are part of almost everything we do, be it at work or during our free time. In all cases we want to have a safe, comfortable and fulfilling life in the right social context. The Digital Life chapter covers the intelligent (and preferable anticipating) applications that support our lives wherever we are and whatever we are doing.

Due to political, demographics and climate trends, Europe is facing major challenges across those spaces, for security, safety, privacy, mobility, efficient energy consumption, etc... The ubiquitous availability of smart devices and the advent of new technologies like IoT (Internet of Things), 5G, AI (Artificial Intelligence) with DL (Deep Learning), VR (Virtual Reality) and AR (Augmented Reality), BCI, Robotics and the like will shape new ways of how people interact with the world and with each other. The 24/7 always-online culture resulting from the ubiquitous connectedness has empowered citizens, they have evolved from consumer to prosumer (such as on YouTube), maker communities have emerged (enabled by the advent of 3D-printing) and simple initiatives as Neighbourhood Watch groups (based on WhatsApp) allowed citizens to enhance their own security. More intelligent, secure and user centred solutions are necessary to meet Europe's challenges, while keeping up with societal needs in a sustainable way, guaranteeing citizen's privacy and reaching broad acceptance in the public.

Four Major Challenges have been defined to ensure safe, secure, healthy, comfortable, anticipating and sustainable spaces, in the personal, private, professional and public context.

10.2. Introduction

The Digital Life is at the heart of a modern smart society and hence tightly related to the overall need of "liveability", which implies all Maslow's hierarchy of *needs*: physiological (sufficient housing, food, energy, etc.), safety (individual protection from external threads), love and belongingness (social inclusion and recognition) and self-fulfilment (artistic expression). Given the state of the planet, there is also an underlying requirement of sustainability. In this context, importance of rights in the digital life domain brings new challenges related to technology implementation, Internet access for all, trust, security, safety, privacy, surveillance and encryption, awareness, protection and realisation of needs and rights

Major Challenges

The Major Challenges aim to improve our Digital Life and are associated to the spaces we live in:

1) Ensuring safe and secure spaces
2) Ensuring healthy and comfortable spaces
3) Ensuring anticipating spaces

4) Ensuring sustainable spaces

Nowadays and certainly in the next years, we need to improve drastically our safety and security requirements to live comfortably to enjoy many healthy life years. Furthermore, comfort and acceptance of application can be further enhanced through anticipation. And above and beyond this, sustainability is a key prerequisite.

The table below shows the different Major Challenges that address the needs of people for the various spaces identified. This results in the following sixteen innovation areas (examples given):

Identified spaces:	Public space	Professional space	Private space	Personal space
Characteristics: Major Challenges:	*in a public environment, with anyone*	*in the work environment, with your colleagues*	*in the home environment, with your family*	*with yourself*
Safety & security	Public safety Emergency and crowd mgnt.	Access control	Anti-burglary	e-Wallet Biometrics
Healthy & Comfortable	(indoor) navigation	Healthy office Productivity	Home Assistant	Personal assistant Quantified self Media content consumption
Anticipating	Traffic mgnt. Asset tracking	Adaptive work space	e-Butler	Coaching wearables
Sustainable	Energy saving Water saving Air-pollution	Carbon neutral offices	Off-grid living Micro housing	Sharing rather than owning

Figure 24 - Major Challenges

These imply ample business opportunities for Europe in related application areas, *for example*:

- Anti-burglary solutions and comfortable domotics at the Smart Home
- Energy saving and productivity enhancers in Smart Buildings
- Public safety and crowd management in Smart Cities

Innovative solutions and services called for in this context may either be completely new (e.g. hologram based 3D-video communication) or based on existing systems that are extended, bridged or merged. (e.g. integrating autonomous service vehicles and fleets of surveillance drones to assist on massive gatherings in urban management solutions and/or disaster recovery).

10.2.1. Vision

10.2.1.1. SAFETY & SECURITY

In our daily lives we expect our environment to be safe, meaning that it is designed and managed to cause no harm, and to be secure, meaning that is difficult to be attacked by external agents. These requirements are applicable in all our living areas, at home, while walking in our city, attending an event, exercising, working or travelling. Safety and security are always moving targets since, beside the known threats, new forms of cyber-crime and terrorism are constantly emerging.

New systems deployed, should at least not decrease the level of safety. With more digital devices connected to the Internet of Things, safety of these connected systems cannot be taken for granted and requires careful planning. It also provides new opportunities for cities to enable active participations by its citizens like neighbourhood watch groups.

Digital Life brings a paradigm shift for the concept of trust as an element with multiple dimensions, combining, for example, privacy, security reliability, availability, and integrity with human and machine behaviour. In this context, there is a need for greater understanding of how individuals interact with machines and how machines/things interact with other machines/things with respect to the extension of trust to assure a safe and secure environment that combines elements of physical, digital and virtual worlds.

The vision is to provide products and solutions that help to ensure high levels of security and safety wherever we are, while at the same time ensuring an adequate level of data protection to ensure privacy.

New surveillance systems based on AI could help in the early detection of threats or alarm conditions of all sorts (from accidents, burglary, vandalism, or terrorist attacks), while other technologies (like augmented reality and advanced robotics) will help to bridge the gap between the virtual and the real world offering new ways for the users to access the services.

Given the ever-increasing dependency on digital products and online services much attention must be paid to address the demand for a permanent uptime and the vulnerability in case of failure. This also implies an increasing need to have a high data rate communications infrastructure that can offer continuous secure and reliable communications.

10.2.1.2. HEALTH & COMFORT

The pervasiveness and the increasing proliferation of digitalisation in different application domains is an enabler for innovative environments. The ever-smarter environments in which people will live are characterized by a high degree of heterogeneous interaction, seamlessly providing services to ever better support of our habits and actions for health, comfort and leisure.

We want to foster these smart spaces, envisaging the expected benefits they can provide, also on health, comfort and leisure:

- At personal space: improving the awareness of our body condition, to external or internal stimuli. Smart systems can provide support for disabilities or a personal coach and trainer to identify behaviour to be avoided (wrong body position, bad habits) and possible future injury or disorders.
- Smart systems can also offer an immersive experience, on vision, gaming and sensory interaction though VR or AR. Consumers can be offered the Immediacy, Individualization, Interactivity, and Immersion they expect for media content consumption.
- At private space with healthier and more comfortable environment based on personal preferences (on temperature, humidity, air flux) in the context of running activities and clothing: adapting lighting and acoustic quality to one's own well-being sense. Providing capability to comfortably communicate and interact remotely with people, institutions, and sellers, possibly without leaving home.
- At office space, remote connections and large interoperability enable office operations and business opportunities around the world. AR vision and AI will assist operators and workers. Work is made more comfortable and personalized to the actual workers' condition and age.
- At public space, a smart guidance system will interact with the public showing relevant information on promotion, on opening hours, or tourist info. Augmented reality can extend what we see in meaningful way and provide new experiences while visiting a city and/or a museum. Also, social media can help to increase safety in public spaces. For instance, alignment of the time and place of "walking the dog" with others in the neighbourhood.

These are just a few examples for the implementation of the Digital Life. New products and solutions will make our everyday life healthier and more comfortable and should enhance social cohesion through digital inclusion.

10.2.1.3. ANTICIPATION

The increasing awareness of the smart environment allows observations of behaviour to be extrapolated into profile-based predictions. Such predictions can be used to anticipate events and offer an appropriate service at just the right moment (before asking) which includes user-friendliness, usability and usefulness and calls for contributions from the social sciences)

- In a personal space: anticipation can be provided through a digital watch or other personal coaching device (serving as a kind of "digital twin") , including cradle-to-cradle and circular economy aspects. remarks for self-improvement activities such as fitness, diet, set goals.
- In a private space with trusted people: anticipation can imply the e-butler functionality by providing suggestions for recipes and meals, or entertainment/gaming in-house or external, based on the proclivities of the individuals in the group.

- In an office space with colleagues: anticipation can be based on asset tracking, organizing activities under consideration of availabilities, absence and replacement.
- In a public space: anticipation can be provided through smart traffic management and/or asset tracking, considering empirical values derived from analysis of historical data. This also holds for retail environments, both physical and virtual.

10.2.1.4. SUSTAINABILITY

Based on the motto of "Towards a sustainable Digital Life" the vision for this Major Challenge is to introduce new digital products that are contributing to a sustainable life style in all areas of human life, including cradle-to-cradle and circular economy aspects. Energy consumption has increased year over year. Smart products and IoT devices for a Digital Life will help to revert this trend. In particular, we are addressing the following spaces:

- Sustainable personal spaces: Optimized energy consumption with feedback / reminders / coaching / guidance to users about usage and waste of resources as part of the "quantified self" (incl. efficient charging of smart device and wearables) …
- Sustainable private spaces: Comprehensive assessment of resource usage to identify largest areas of consumption. Offer solutions for lighting, heating, computing with reduced usage of energy and other resources. Also, homegrown vegetables and city farming systems.
- Sustainable professional spaces: Providing IoT/smart systems that supports the digital business life with the minimum amount of resources (energy, water, paper, …) ensuring a highly efficient, productive, and sustainable working environment. Furthermore, the reduction of (food) waste in supermarkets and restaurants.
- Sustainable public spaces: Traffic management for efficient use of energy supporting different type of mobility. Smart water management to protect resources. Intelligent management of energy at public places such as football stadiums and railway stations, including smart street lighting. Promoting green areas in the cities and enable citizens to provide their own sustainable solutions.

10.2.1.5. GAME CHANGERS

Europe is in the middle of a changing world with an ageing population that is living more and more in urban environments. This is challenging the preservation of natural resources, air quality, clean and efficient transportation, new infrastructures, and the like, all in relation to the quality of life. Together with a climate change in progress this poses major challenges.

Next to the technological advancements, important driving forces for futures changes are the general desire for access to any information and the adaption to rapidly changing circumstances. Moreover, the increasing possibilities to take control as (a group of) citizens without authority involvement can have far reaching consequences (e.g. bitcoin, twitter, maker communities, …).

The general trend in which the services providers are becoming ever more the mere carrier of the demand & respond of services without requiring the ownership of the resources themselves potentially impacts everyone's life and habits. Additionally, instruments provided by the pervasive digitalisation and enlarged interconnection reinforce the convergence

between traditionally "institutional" and/or "professional" service providers and less "professional" and possibly "occasional" or "temporary" providers. The obvious examples concern B&B and taxi services, but it is also in the concept of prosumers within a smart grid. The trend on mobile digital payment, triggered by EU regulation PSD2 (2015/2366/UE) is further stimulating this.

The in-vehicle transit / on-the-move experience will increasingly be a defining feature of the future of mobility. As shared and autonomous mobility proliferate, a tremendous opportunity arises for companies seeking to sell content, entertain, and generally enhance the time spent in-transit. "Experience enablers"—content providers, in-vehicle service providers, data and analytics companies, advertisers, entertainment equipment providers, and social media companies—will clamour to make the in-transit experience whatever we want it to be: relaxing, productive, or entertaining[32].

Many anticipating devices will be wearables. In the US there used to be a demographic divide among the users, mainly in the age bracket between 25 and 54 and encompassing the fittest users. Recently the market grows and opens up to younger consumers and those doing moderate or no exercise[33]. The smart phone as the only connection to cloud and internet will be complemented and partially replaced by wearables. These in turn will become the most personal devices. They will replace items such as watches, GPS, glucose and blood pressure monitoring, identification documents and will support the user in relevant situations.

	Positive factors	**Negative factors**
Internal factors to the EU ECS industry[34]	**Strengths:** Presence of strong industrial players in EU Citizen protection by EU through privacy regulations Much creativity in EU Great design capabilities in EU Experience in embedded systems	**Weaknesses:** Fragmented market across countries Limited start-up / VC culture Few social media companies in EU Personalised cloud providers from US …
External factors to the EU ECS industry	**Opportunities:** Ubiquitous availability of smart phones Low-cost availability of accurate sensors Advent of IoT, 5G and AI/DL Advent of VR, AR, BCI, Robotics, … Advent of self-parking car, …	**Threats:** Ageing population Rural-urban migration Climate change Competition from other continents …

Figure 25 - SWOT analysis / game changers

[32] The future of mobility: What's next? https://dupress.deloitte.com/content/dam/dup-us-en/articles/3367_Future-of-mobility-whats-next/DUP_Future-of-mobility-whats-next.pdf

[33] Wearable technology and the IoT, Ericsson

[34] EU industry here means the full Large Industry + SME + RTO + University eco-system

10.2.1.6. COMPETITIVE SITUATION

There are many different market segments involved. Most of them are dominated by US companies, but with a strong competition from the EU and Japan. In a recent study, five of the top ten global suppliers for smart cities are American, three European and two Japanese.

However, there are some markets were the situation is quite the opposite, like for example the professional mobile radio that the leader is a European company, or the surveillance segment were US and European companies account for one third of the market share each.

- The United States tend to compete in the field of sustainability through corporate-driven R&D&I, science and technology. For instance, large companies such as Google and Apple invest in home-automation (e.g. Nest and HomeKit), expecting benefits for the consumer primarily in convenience and home security but at the same time unlocking a huge energy-saving potential if properly used.
- China has a mixed open/controlled model of central government-driven science, technology and corporate RDI aiming at sustainable growth. It will spend 361 B$ on renewable energy by 2020 and 146 B$ on semiconductors in "Made in China 2025". These gigantic programs will enable smart systems that support sustainability according to China's positioning as world's climate leader and they will flood the world market just as smart phone are doing this today.
- The Japanese science and technology agency JST aims to realize a sustainable society by developing game-changing technologies for a low carbon society and solving food and water issues. IoTs are used in Smart City projects in Japan initially as smart meter. Gradually the system will be linked to house hold appliances and individual as well as public transport to create sustainability via big data
- In China IoT is announced as one of the strategic industries by the China's State Council. Focus points among others is Smart Cities, Environment and Sustainable Development and Big Data also in the MC2025 program. Surveys in major markets worldwide show that purchase intention for wearables such as fitness trackers, allergy alert scarfs, emotions sensing tattoos is highest for Chinese consumers[35].
- Japan has a long tradition in research on robotics to compensate effects from demographic development. Latest items are exoskeletons controlled by bio-electric signals from the user to lift heavy loads. Vision of smart home
- Taiwan government supports academic edge AI chip development project See http://www.design-reuse-embedded.com/news/201708054#.WZ8W4mcUlD8
- Qualcomm boosts machine learning capability by buying Scyfer (same link as above)
- AI Sees New Apps, Chips, says Qualcomm (same link)
- (Leisure) Creative Industries are a major player in the EU economy: the industry provides 7.7 million jobs in 2.2 million companies of which 85% are SMEs creating yearly revenue

[35] Wearable technology and the IoT, Ericsson

of 625 billion Euros[36]. The aggregate revenues for all media technology products and services providers in 2016 were 50.97 billion Dollars, where Europe and the Middle East together accounted for 43.3%, the Americas for 37.6% and Asia Pacific for 19.1%[37].

10.3. Major Challenges

10.3.1. Major Challenge 1: Ensuring safe and secure spaces

First and foremost, the spaces we live in must be safe and secure, both physically and virtually.

10.3.1.1. SCOPE AND AMBITION

The scope of this chapter covers many different locations:

- At personal space: Personal data and privacy should be should be protected by developing and deploying the proper security and private mechanisms to avoid malicious tracking and attacks in the personal devices such as wearables, tablets and new others.
- At private space: Although we usually feel safe at home, statistics show a high number of physical accidents happens at home, being the main cause falls, poisoning and drowning. Extra attention should be paid to the higher-risk groups of young children and elderly people. In the virtual domain, own control over personal data storage is necessary for privacy, where people are the owner of their data and decide for themselves whom to give access.
- At professional space: Activities related to smart manufacturing and healthcare are outside of the scope of this chapter, however safety and security in all other work environments are within the scope, covering office environments, agricultural and farming, construction sites, etc.
- At public spaces: Except for transportation, all other activities in public areas in a city are within the scope of this Major challenge.

The ambition of this MC is to provide systems and technologies that help avoid dangerous of harmful situations in any of the above-mentioned environments, while ensuring an early detection and fast managements of the incidents when they occur. The objective is to reduce the number of incidents and their impact while maintaining a low number of false alarms. These incidents include all that is caused by fortuitous accidents and by malicious acts. A critical aspect of the challenge is to ensure an adequate level of privacy for the users.

[36] New challenges in media, content, and creativity sectors in Europe, by Albert Gauthier, Policy Officer Data Applications & Creativity, DG CONNECT, 2016 https://nem-initiative.org/wp-content/uploads/2016/11/ec.pdf

[37] 2017 IABM DC Global Market Valuation Report

10.3.1.2. HIGH PRIORITY R&D&I AREAS

- Emergency management and evacuation systems
- Real-time dynamic malware avoidance and detection systems
- Mission- and safety-critical feature rich communication systems for law enforcement
- Autonomous, dynamic user authentication, authorisation, and trusted relations
- New concepts and architectures for increasing the trustworthy of digital services and platforms
- Distributed AI, cognitive learning and distributed security (based on blockchain technology or other concepts) and,
- Surveillance systems both for indoor private use and outdoor public using advanced video pattern recognition to allow large numbers of resulting video streams to be automatically monitored

10.3.1.3. EXPECTED ACHIEVEMENTS

Reduction of the number of incidents with respect to the current baseline, and mitigation of their impact through the usage of the new technologies, integrated in an emergency management system that enables adequate, well-coordinated response in time.

10.3.2. Major Challenge 2: Ensuring healthy and comfortable spaces

All spaces must support a healthy life, while providing comfort.

10.3.2.1. SCOPE AND AMBITION

Exploiting Smart System Integration capabilities with Cyber Physical System approaches and integrate them into efficient IoT systems is required to provide the right collection of data for a true exploitation of digital analysis and to implement innovative services and appropriate physical actuation. Hence, there is interest in:

- SSI: sensors, actuations, harvesting, power management, miniaturization, embedded computing, communication. etc.…
- CPS: systems of systems, communication protocols and architectures, devices virtualization, networking and ICT, edge computing, etc.…
- Smart data analytics: systems virtualization, digital twin, learning methodologies, taking into consideration that the things belonging to the IoT infrastructure can establish social relationships in an autonomous manner with respect to their owners, which derives from the integration of social networking concepts into IoT, virtual spaces and AR.

The ambition is to raise the awareness on the potential and the (social) impact of smart solutions to be motivated for their adoption in critical situations and their essence in normal life. For example, providing a vehicle that is responsive to the driver's physiological status (fatigue, alcohol rate…) is part of assisted driving and a safety issue from the point of view of the vehicle's occupants, but for the other surrounding drivers and nearby pedestrians these smart solutions make their trip more comfortable and safe. Research and development should

address the future implementation of Digital Life ensuring a right, safe and confidential environment in which to improve our quality of life.

The quality of life is also determined by the way consumers spend their leisure time, at home and on the move. Mobile technology is transforming the way people around the world consume media content, and will continue to drive the expansion in overall media consumption. More technological advances will make it possible to place audiences in the middle of the action and to offer them *Immediacy, Individualization, Interaction and Immersion*.

10.3.2.2. HIGH PRIORITY R&D&I AREAS

- Development of sensors devices to measure and digitize physical quantities through low-cost, energy efficient, highly accurate implementations i.e. inertial and micro-nano-bio systems, air sensors, water quality sensors and more generally resource quality and environmental variables measurements, monitoring of infrastructures, skin and tactile sensors, utility smart metering, etc.
- Compact, energy efficient actuators to allow a better physical activation using new mechatronic technologies, robotic concepts, self-navigating features and haptic interaction.
- Sensors and actuators data fusion technology and application of methodologies like machine learning and adaptive solutions in order to improve the quality of the information derived from the data and the interaction with the users.
- Innovative solutions that allow a larger diffusion of the physical edge nodes, making them more performant on communication, data elaboration, and power management, so to not require any wire connections to install
- Improvement on interoperability among different domains to make appropriately (vs privacy, security and safety) available the awareness of each context to the other. Multi-protocol hardware and software platforms, standardization,
- Improvement on Wireless networking capability (on throughput, on consumptions, reliability, etc.) from Personal Area Network and Local Area Network up to Wide Area Network and promote the re-use and conversion of replaced telecommunication network for sensing/actuating, metering and IoT applications.
- For media content creation the move to IP, use of virtualized, software-based environments, UHD, and Virtual Reality will continue to alter the landscape of media. Humans and machines are becoming more interchangeable in many areas as data-driven automation increases. Data-driven automation will enable increased efficiency in live productions and new business models for multi-platform content delivery.

10.3.2.3. EXPECTED ACHIEVEMENTS

Development of future solutions that contribute to healthy and comfortable life:

- Human-centric, open interaction platforms including wearables and portables, integrating personal IoT devices and smart spaces (personal, office, public) to provide new kind of services and personal experience
- A large diffusion and adoption of IoT devices for smart home, smart building, smart office, smart grid, smart manufacturing ("SmartX"), favoured by improvement on wireless communication and on power harvesting capabilities
- Collaborative robots ("cobots") and cooperation with other machines and humans
- Integration of physical things/objects with augmented reality and virtual spaces
- Distributed AI, AR vision and virtual spaces
- Smart media content generation and multi-platform content delivery
- Automatic adaptation to operator conditions and operator age
- Advanced sensors for autonomous vehicles, distributed augmented reality

10.3.3. Major Challenge 3: Ensuring anticipating spaces

Additional added value can be provided through anticipation mechanisms that provide the service *before* it is explicitly required.

10.3.3.1. SCOPE AND AMBITION

The scope of ensuring anticipating spaces is formed by smart systems such as personal devices and robots that facilitate daily routines in all aspects of the digital life. These range from smart phones for personal organization, robots at home, and large-scale systems to organize life at work and the city. The ambition is to provide systems that are pro-actively support individuals (and society) in their daily affairs. Anticipating systems and services will have a sense of what is desired and required.

10.3.3.2. HIGH PRIORITY R&D&I AREAS

- Personal space: the smart phone can provide personal anticipation at the personal level.
- Private space: robotics in care and smart assisted living environments, enabling elderly people to lead a self-determined life. Through observation of habits, regular events, and daily routines upcoming needs for support can be predicted.
- Office space: anticipate and prepare events incl. reservation of meeting rooms, catering, travel booking providing of necessary elements, etc.
- Public space:
    - Providing navigation tips to avoid congestions, indication of free parking space, self-parking, street lighting on demand/need, etc.
    - Identification of the emergence of potential dangerous situations, technologies that use VR and AR to provide education of security measures / crowd management (situation awareness, pedestrian circulation, …)
- Further development of data analytics (performed at edge computing and machine learning capabilities) to realise the anticipation functionality.

10.3.4. Major Challenge 4: Ensuring sustainable spaces

The state of the planet implies extra requirements to ensure survival in the long run. These include not only carbon neutrality, but also the managed use of scarce water resources and the availability of affordable housing in large megacities.

10.3.4.1. SCOPE AND AMBITION

- The scope of the research and development efforts cover electronic components and systems to support smart energy, smart lighting, smart water management, and other "green" facilities in smart cities, smart buildings and smart homes.
- One important goal is to create a wide acceptance for energy saving products and services by ease of use and transparency of functionality in all aspects of the digital life.

10.3.4.2. HIGH PRIORITY R&D&I AREAS

These are priorities for the R&D&I on technologies which are enabling the applications:

- Multi-modal traffic and parking management in congested areas (up to 40% of traffic in these areas is created by searching for parking spaces)
- Multi-modal (intermodal) traffic in sparsely populated areas (e.g. autonomous vehicles called on demand from/to the stations of the backbone railway line, since frequent public bus transport does not pay off, etc.), "Tram (small train units) on demand" etc.
- Overall transport automation in European regions (automated "robot taxis" vehicles complementing high speed railway lines, freight transport on last mile by automated vehicles or by small autonomous train units, etc.)
- Solutions addressing circular economy concepts to identify and separate recyclable material over the life-cycle of a product
- Smart sensor evaluation to reduce communication power (in sensor, smart hub/gateway, edge processing or cloud)
- Monitor life cycle of materials as part of circular economy to save resources
- Concepts for smart street lighting (lowering energy usage while enhancing safety)
- Embedded air quality monitoring (particles/gas) solutions for efficient energy usage e.g. ventilation of buildings
- Integrated sensors to detect leakage in ageing infrastructure
- Systems solutions for sustainable agri-food industry preserving natural resources, reducing production waste, minimize the use of pesticide and/or facilitate the use of organic products to shift more and more to an organic production.
- Energy efficient horticulture lighting and animal-friendly poultry lighting
- Serious gaming and gamification for educational purposes
- Context awareness for energy reduction and improved living
- Smart sleep mode for smart devices: Wake-up functionality to conserve energy
- Assessment tools for energy-saving technologies: well-to-wheel, total energy consumption including production phase as support for decision making

10.3.4.3. EXPECTED ACHIEVEMENTS

Development of future solutions that contribute to sustainability and preserve natural resources

1) Smart energy monitoring by IoT devices embedded within Distributed Energy Resources
2) Extended battery life by ultra-low-power techniques
3) Creating front runners for sustainable Digital Life, i.e. projects in selected cities
4) Energy efficient smart parking management systems, reducing traffic congestion
5) Energy efficient public safety systems, including alarming and evacuation of crowds (in a station or stadium) through personalised digital services

10.4. Timeframes

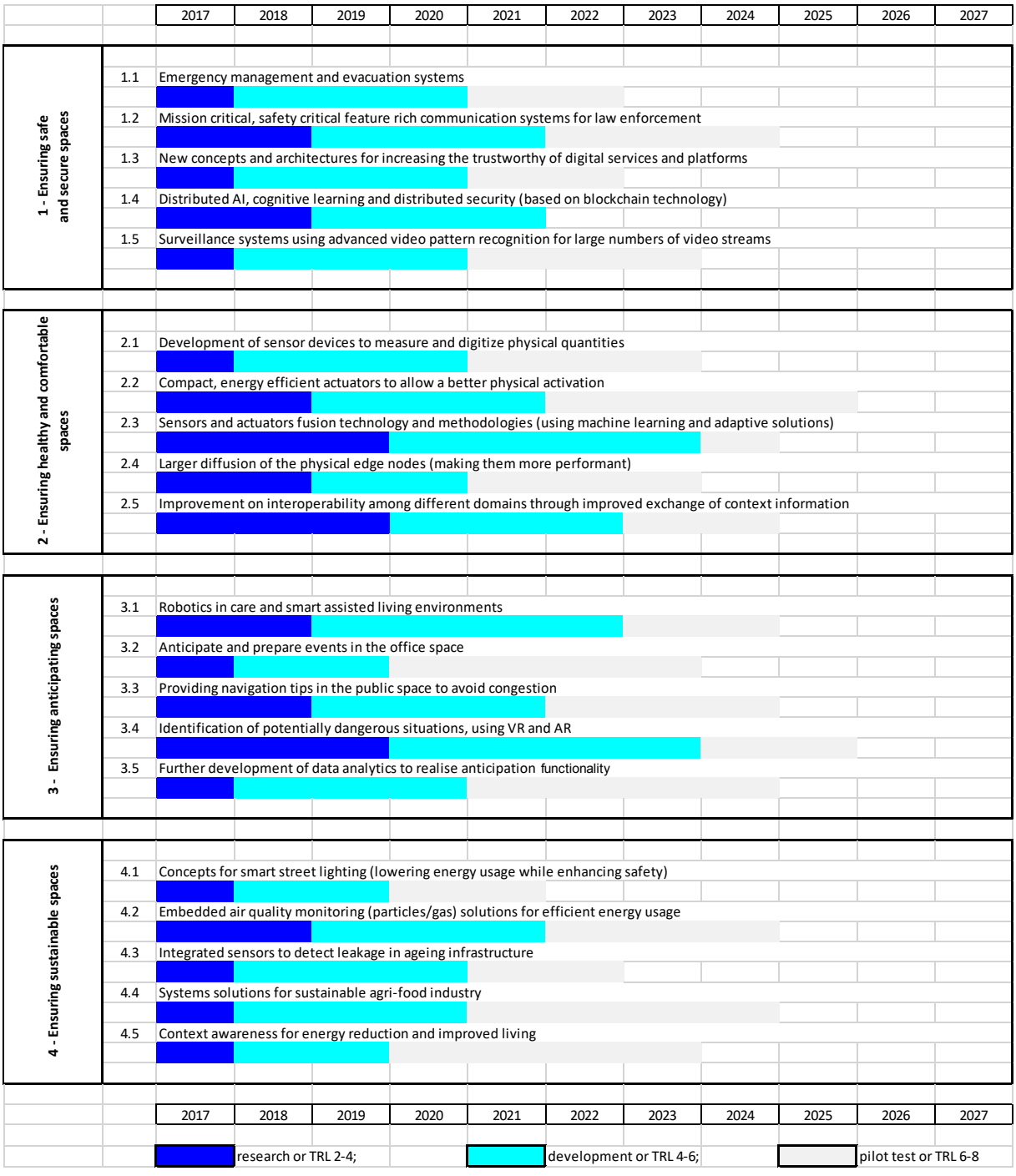


Figure 26 - Digital Life roadmap

10.5. Synergies

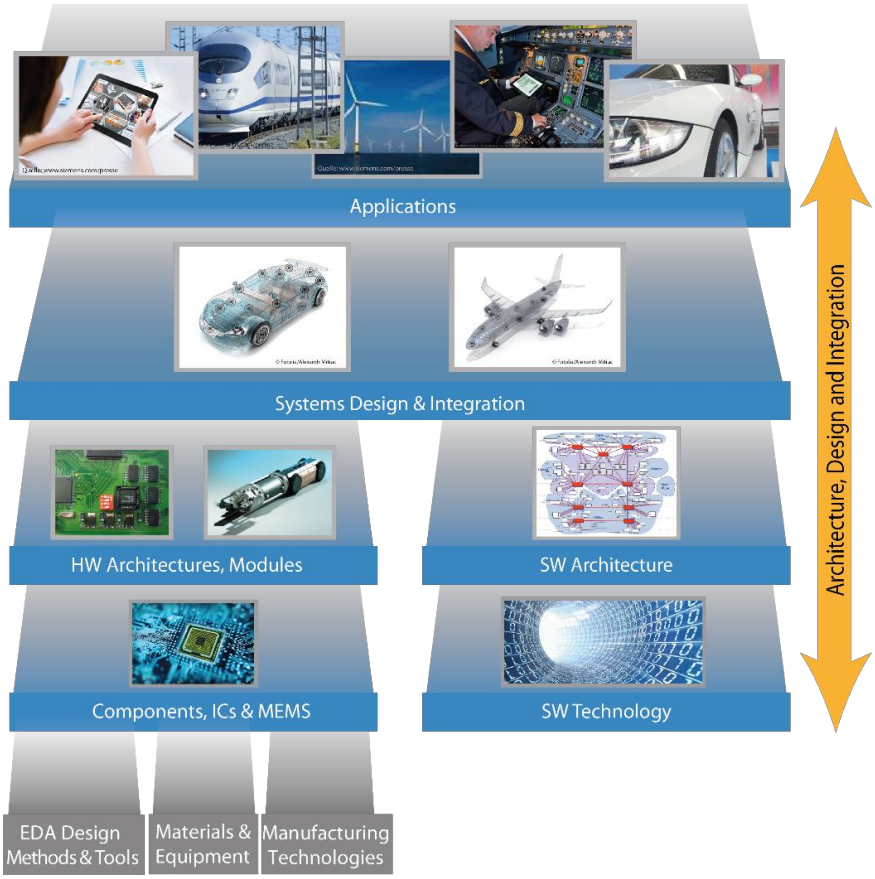
With three other ECS SRA chapters there is some synergy, which has been delineated as follows:

- Health & Wellbeing: Where HealthCare aims to cure people from diseases, wellbeing implies measure to keep healthy people healthy. The Major Challenge “Ensuring healthy and comfortable spaces” will contribute to the aim to keep healthy people healthy by Digital Life supportive products and services.
- Multimodal Transportation / Mobility: Where the transportation chapter will mainly address infrastructure related aspects, the Digital Life implies “being on the move” from time to time. The aspects address by the Major Challenges for Digital Life also apply when being on the move.
- Energy: Electrical Energy is a pre-requisite of a Digital Life, as smart devices live from it. Although in general energy generation and distribution is a different area, energy scavenging of IoT sensors and actuators, energy storage and wireless charging of smart phones and other wearables can be essential element of a Digital Life.

11. Systems and Components: Architecture, Design and Integration

11.1. Executive Summary

Effective design technologies and (smart) systems integration, supported by efficient and effective architectures, are the ways in which ideas and requirements are predictively transformed into innovative, high quality, and testable products, at whatever level of the value chain, shown in Figure 27.



The word **system** is used in this context for the respective highest level of development that 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 Cyber-Physical Systems of Systems and products, involving software and hardware parts. A "system" designed and implemented within a given development process may be integrated as a "component" into a higher-level "system" within another development process.

Figure 27 - On every level of the value chain, the top-level artefact to be developed is usually called "the system", even if it is used as a component on higher levels of the chain

These aforementioned technologies aim at increasing productivity, reducing development costs and time-to-market ensuring the level of targeted requirements such as new functionalities, quality, system level performance, cost, energy efficiency, safety, security, and reliability.

Design Technologies include methodologies involving hardware and software components, design flows, development processes, tools, libraries, models, specification and design languages, IPs, manufacturing and process characterisation. Mastering design technologies and extending them to cope with the new requirements imposed by modern and future Electronic Components and Systems (ECS) are highly important capabilities of European industries to ensure their leading position in ECS

engineering. To ensure this leading position, the creation of efficient, modular **architectures** and digital platforms is needed, which enable the system's intended functionality at the required quality, and support efficient, cost-effective validation and test methods.

Physical and Functional Systems Integration (PFSI) is one of the essential capabilities that are required to maintain and to improve the competitiveness of European industry in the application domains of ECS. Although, in practice, PFSI is often geared towards specific applications, the materials, technologies, manufacturing and development processes that form part of this domain are generic. PFSI is hence an enabling technology in the area of ECS that needs to be further addressed by research, development and innovation (R&D&I), filling the value chain, the gap between technology and application, and moving innovations into products, services, and markets.

The **objective** of the proposed R&D&I activities is to leverage progress in **Systems and Components Architecture, Design and Integration Technologies** for innovations on the application level.

11.2. Relevance

Effective architectures, design methods, development approaches, tools, and technologies are essential to transform ideas and concepts into innovative, producible, and testable ECS, and products and services based on them. They provide the link between the ever-increasing technology push (More Moore (MM) and More-than-Moore (MtM), increased connectivity and its potentials and the demand for new innovative products and services of ever-increasing complexity that are needed to fulfil societal needs, while at the same time aiming at increasing productivity, reducing development costs and time-to-market, and ensuring the level of targeted requirements such as on quality, performance, cost, energy and resource efficiency, safety, security, and reliability.

Design technologies enable the specification, concept engineering, architecture exploration and design, implementation, and verification of ECS. In addition to design flows and related tools, design technologies also embrace libraries, IPs, process characteristics and methodologies including such to describe the system environment and use cases as well as Reference Architectures, Digital Platforms, and other (semi-) standardized building blocks. Design Technologies involve both hardware and software components, including their interaction and the interaction with the system environment, covering also integration into (cloud-based) services and ecosystems.

Moreover, the importance of software in ECS is increasing since the current trend includes the shift of features from the hardware to the software. This trend aims at standardizing more the hardware (reducing the costs) and creating more advanced and customizable features in software (allowing also easier updates and improvements). This shift is required to meet the needs of the market that requires not only safety and security but also short time-to-market and development cycles. Systems architectures, design technologies and especially validation and testing processes have to follow this shift to enable European industry to meet the continuous changes of the market.

Future smart systems will feature new applications, higher levels of integration, decreased size, and decreased cost. Miniaturisation, functional integration and high-volume manufacturing will make it

possible to install sensors in even the smallest devices. Given the low cost of sensors and the large demand for process optimisation in manufacturing, very high adoption rates are possible; in fact, perhaps around 80–100% of all manufacturing could be using IoT-based applications by 2025. Improved integration technologies and miniaturisation will enable patient monitoring devices for a broad range of conditions. Cost efficient manufacturing will increase the market penetration of advanced driver assistance systems and help reducing traffic mortalities.

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

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

11.2.1. Game Changers

While the objectives outlined above have been pursued even for the very first instances of electronic systems embedded into products, a number of new demands are coming from the increased complexity of ECS to be designed. Even more critical is the appearance of 'game changers' arising from the stepwise changes in system evolution. Among these 'game changers', many of the ones described in Section 0 apply for Architecture, Design and Integration Technology, too: Safety and Security (c.f. Sec. 0.2.3, and also Chapter 13) are overarching goals that we have to target. Increased connectivity of ECS, increased importance and capabilities of Software including the advent of Artificial Intelligence and learning systems (c.f. Section 0.2.1) all increase the complexity of the design and integration task and require new methods, processes and tools support their cost efficient design, development, integration, and verification and validation.

Among the 'game changers', the most critical will be:

- **Autonomous networked systems**: the introduction of IoT implies that ECS are becoming increasingly networked with each other as well as with 'cloud-based' services, creating machine-to-machine interactions without any human intervention in the control loop, for example in fully automated driving. Besides the need the added complexity of interfacing different subsystems with different standards, the systems' rising complexity and increased automation, implicates increased severe

safety risks. New techniques are required, such as scenario and model based safety analysis, online safety assessment, re-certification, architectural support not only for the functionality but also for verification, and many similar.

- **Self-evolving systems**: ECS and especially Cyber-Physical Systems (CPS) exhibit an increasing level of automation (up to autonomy). Machine learning, Neuromorphic architectures, Artificial Intelligence, now entering the field of possible, coupled with decision making capabilities and handling of uncertainty, to match an evolving environment, are proposing an enormous challenge for safe design, Verification and Validation (V&V) technologies and testing.
- **Design for a larger world**: ECS span more than one application domain. Example domains include Embedded Systems and the Internet / Cloud, or consumer electronics and assistance systems in cars. Moreover, ECS based products in general have a long lifetime (up to several decades, e.g. for airplanes), during which they might encounter new situations in the environment in which they are meant to act, and new unforeseen requirements to their behaviour (e.g. changing regulations, etc.). The design therefore has to expand its scope including the full ECS system, its application environment and its evolution. All the foreseen lifecycle of the product must be covered, considering also that its components could have different lifecycles/lifetimes.

Severe challenges are coming also from the already present trends in ECS evolution. Among others:

- **Human-Machine-Interaction:** ECS and especially CPS interact with each other and with human beings: Human Machine Interaction, Human Machine Cooperation and adaptation of machines to human needs thus are increasingly important topics in systems design.
- **Personalised functionalities and Variant Management:** ECS based products are often highly configurable to adapt to users' needs and requirements and thus product variability is vastly increasing. The challenge here is to adapt and enrich the Design Methodologies (including the Software Engineering ones) and have corresponding tools to support these changes.
- **Increasing importance of software:** Features are shifting from hardware to software to improve adaptability, upgradability and evolvability. Therefore, software engineering (approaches and tools) is of increasing importance and needs to be adapted to the specific needs of ECS.
- **Increasing speed in development processes** – e.g. consumer technologies for industrial, infrastructure or automotive applications due to performance and scalability

These game changers for developing modern and future ECS give raise to seven 'Major Challenges', that are detailed in Section 6.3.

11.2.2. Competitive value

Traditionally, European industry has a leading position in Systems Engineering, allowing it to build ECS based products that meet customer expectation in terms of functionality as well as quality. Design technologies – processes and methods for development, testing and ensuring qualities of the Hardware, the Software and the complete system, as well as efficient tools supporting these – are a key enabler for this strong position. Facing the new requirements and game changers explained above, it is of utmost importance for these industries to put significant resources into R&D&I activities to maintain and strengthen this leading position and to enable them to satisfy the needs of the different domains while reducing the development cycles and costs.

Europe also has very strong system houses producing complex innovative high-tech designs for products in the areas of aeronautics, automotive, industrial applications and manufacturing, healthcare, and communications. To maintain their world-leading positions, a continuously push for improved electronic systems at increasing levels of automation is essential while sustaining high quality in parallel. This means that system complexity is continuously increasing and the probability of design errors is growing.

Large EDA (Electronic Design Automation) companies currently provide mainly tools and methodologies for specific design domains (digital macros, analogue & RF macros, SW, package, PCB) which are only roughly linked and mostly not focused on European needs in design technology. Higher design levels are not well covered, even though some initiatives for the support of higher levels of abstraction do exist. Large system and semiconductor companies normally combine available (partial) solutions with (non standardized) in-house solutions. A comprehensive seamless open and extendable open design ecosystem across the whole value chain has thus to be created, especially for supporting heterogeneous applications. Yield, heat, and mechanical stress need to be addressed in more holistic way. This will become increasing critical as parts are further embedded into packages (e.g. SiP, SoC) and opportunities for re-work, inspection and repair diminish. Design for testability and manufacturability are critical for the same reasons with a need to model and simulate processes as well as product behaviour.

To compete with low labour-cost countries, it is of topmost importance for Europe to develop and offer, at the right time, sophisticated feature-rich innovative products with the superior performance and quality needed to justify a higher price tag. Time-to-market is of crucial importance, since even a one-month delay in market introduction can result in a significant loss of revenue in fast moving markets, or in the complete loss of seasonal consumer markets. Life cycle cost analysis is also critical to ensure that installation, operation, maintenance, re-configuration over project life, re-cycling, etc. are all taken into account. Europe's competitiveness in ECS offerings will be enhanced for many applications when such a holistic assessment is undertaken.

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. 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 and decreased cost. 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.

Tackling the Major Challenges introduced in Section 3 will enable European Industry as a whole to benefit from the progress made in innovative electronic components and systems.

11.2.3. Societal benefits

Society desires high-end technologies on a large scale and at affordable cost. Within the global trends of becoming a world where everything is connected, everything is smart, and everything is safe and secure, design technologies and physical and functional systems integration are two of the key enablers for this development. First, they enable modern and future ECS based products – Cyber-Physical Systems, components of 'Information and Communication Technology' and thus of the 'Internet of Things' (IoT), smart devices – with the required functionality and quality to be built at all. Second, they assure products meeting and exceeding the required quality – i.e., products that are safe and secure, dependable and reliable, recyclable, serviceable, etc. – thus allowing these products to enter the market and increasing user's trust and confidence in using these products. Third, they enable cost efficient production of these products, thus making them affordable. Last, but not least, they allow increasing 'smartness' of products and therefore market opportunities are huge. The design technology bottlenecks have to be removed to enable the design of all the ECS necessary to meet the societal needs of a growing population.

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 "Digitalisation" process, both are allowing disruptive improvements in each aspect of human life.

11.3. Major Challenges

Effective and efficient architectures, design and integration technologies are essential for predictively transforming ideas and requirements into innovative, high quality, testable and deployable products on all levels of the value chain. These approaches, supported by valuable verification, validation and testing techniques, methods and tools, aim at increasing productivity, reducing development costs and time-to-market. They ensure the targeted requirements such as new functionalities, quality, system level performance, cost, energy efficiency, safety, security, and reliability. As such, continued development of those technologies is a prerequisite to the realisation of the ever more complex systems required to meet Europe's societal challenges.

Major Challenges in Architecture, Design and Integration are:

- Managing critical, autonomous, cooperating, evolvable systems
- Managing complexity
- Managing diversity

- Managing multiple constraints
- Integrating miniaturized features of various technologies and materials into smart components
- Providing effective module integration for highly demanding environments
- Increasing compactness and capabilities by functional and physical systems integration

These challenges are not disjoint, but strongly interdependent as e.g. diversity and also handling of multiple constraints (e.g. for a required minimum quality of the product) are significantly increasing complexity. Nonetheless, these challenges emphasize the main obstacles that need to be overcome in order to realize the vision.

Furthermore, all challenges commonly face the demand of integrating design technology aspects into an ecosystem for processes, methods and tools for the cost efficient design working along the whole value chain and life cycle.

11.3.1. Major Challenge 1: Managing critical, autonomous, cooperating, evolvable systems

11.3.1.1. VISION

Many new and innovative ECS products 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 and context aware decision making capabilities, in order to fulfil their intended functionality. In addition, they need the capability to evolve and adapt during run-time, e.g., by updates in the field and/or by learning. Building these systems, and guaranteeing their safety, security and certification, requires innovative technologies in the areas of modelling (systems and their environment, humans as operators and cooperation partners of these systems, as well as use-cases, scenarios, etc.), software engineering (quality of the process and the product, development approaches, etc.), model-based design, V&V technologies, and virtual engineering for high quality, certifiable, and (cost-)effectively producible ECS.

11.3.1.2. SCOPE AND AMBITION

R&D&I activities in this challenge aim at enabling seamless and concurrent model-based development methods and tools for critical systems, with a strong focus on V&V and Test activities. Major topics are identified in the areas of Models, model libraries, and model based design technologies, V&V and Test Methodologies and Tools, and (virtual) engineering of ECS.

11.3.1.3. HIGH PRIORITY R&D&I AREAS ON CRITICAL, AUTONOMOUS, COOPERATING, EVOLVABLE SYSTEMS

Topics of Major Challenge 1 are collected in three categories (high priority R&D&I areas), which are described here. For each of the areas, the timelines in section 6.6 contain an elaborated

list of the corresponding R&D&I topics, the full list for each area is given in section 12 of the document, “Appendix to Chapter 11”.

Models, model libraries, and model based design technologies

Topics grouped under this heading include re-usable, validated, and standardized models and model libraries for systems behaviour, systems’ context/environment and humans (as operators, users and cooperation partners). Additional important topics in this area are model based design methods, including advanced modelling techniques for future ECS and extended specification capabilities, all supported by advanced modelling and specification tools.

Verification and Validation (V&V) and Test for critical systems: Methods and Tools

This area comprises model based verification, validation and test methodologies and technologies as well as interoperable tool chains and platforms for critical systems, automated derivation of verification procedures and back annotation, V&V and Test methods for Life-Cycle and in-service phase, and V&V and test methods for adaptive, cognitive and learning systems and autonomous systems.

(Virtual) Engineering of Electronic Component and Systems (ECS)

Collaboration concepts and methosd across groups, organisations, and diciplines for holistic (virtual) Engineering of ECS over the whole value chain is the main topic in this R&D&I area. This includes methods and interoperable tools for virtual prototyping of complex ECS and appropriate Engineering Support (libraries, platforms, and interoperable tools for evolvable, adaptable Open Wolrd Systems, including cognitive and cooperative systems.

11.3.2. Major Challenge 2: Managing Complexity

11.3.2.1. VISION

With the increasing role of electronics systems and especially under the influence of connected systems, e.g. in IoT, CPS, etc., the complexity of new and innovative ECS increases constantly. Better and new methods and tools are needed to handle this new complexity (also considering the increased amount of software used for many of the most complex features) and enable development and design of such complex systems in order to fulfil all functional and non-fucntional requirements, and to get cost-effective solutions thanks to high productivity. This challenge focuses on complexity reduction techniques in the design and analysis of such ECS, in order to increase design productivity, efficiency and reduce costs.

11.3.2.2. SCOPE AND AMBITION

R&D&I activities in this area aim at developing solutions for managing the design of complex ECS in time at affordable costs. It focuses on architecture principles and systems design topics to reduce complexity for design and V&V and test of such ECS systems, methods and tools to increase design efficiency, and complexity reduction techniques for V&V and Test.

11.3.2.3. HIGH PRIORITY R&D&I AREAS ON MANAGING COMPLEXITY

Topics of Major Challenge 2 are grouped in four categories (high priority R&D&I areas) described here. For each of the areas, the timelines in section 6.6 contain an elaborated list of the corresponding R&D&I topics, the full list for each area is given in section 12 of the document, "Appendix to Chapter 11".

Systems Architecture

This area groups extended methods for architectural design – support for systems with thousands of components, metrics for functional and non-functional properties, and early architectural exploration – and design methods and architectural principles, platforms and libraries supporting V&V, Test and Lifecycle Management of complex, networked ECS, including support for Self-management, self-awareness and self-healing as well as cognitive and adaptive systems.

System Design

Design and Analysis methods for Systems and Components are the focus of this area. This includes support for multi-/many-core systems, support for IP Modelling, component-based HW/SW co-Design approaches and methods and tools for virtual prototyping.

Methods and tools to increase design efficiency

Seamless and consistent design and tool chains for automated transfer (extraction, synthesis, …) of system design description into functional block, strong support of package, board and sensor/MEMS co-design, new methods and tools to support new design paradigms (like multi-/many cores, increased software content, GALS, neural architectures, etc.), new technologies (FD-SOI, graphene, etc…) and new approaches to handle analog/mixed design are the main topics of this area.

Complexity reduction for V&V and Test

Coping with the complexity of V&V and Test methods for modern ECS is the focus of this area. This includes techniques (and tools support) for (automatic) complexity reduction, methods and tools to support scenario based V&V and Test, virtual platforms in the loop and similar, as well as prove techniques to assess the safeness and soundness of these complexity reduction techniques.

11.3.3. Major Challenge 3: Managing Diversity

11.3.3.1. VISION

In the ECS-context a wide range of applications have to be supported. With growing diversity of today's heterogeneous systems/designs requiring integration of analogue-mixed signal, digital, sensors, MEMS, actuators/power devices, transducers, storage devices, domains of

physics as for example mechanical, photonic 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 multi-layered connection of the digital and physical world is needed (for real-time as well as scenario investigations).

11.3.3.2. SCOPE AND AMBITION

R&D&I activities in this area 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, thermal, magnetic, chemical, and or optical.

11.3.3.3. HIGH PRIORITY R&D&I AREAS ON MANAGING DIVERSITY

The main R&D&I activities for this challenge 3 are grouped in four categories (high priority R&D&I areas):

Multi-objective optimisation of components and systems

The area of Multi-objective optimisation of components and systems comprises integrated development processes for application-spanning product engineering along the value chain including modelling, constraint management, multi-criteria, cross-domain optimization and standardized interfaces). Furthermore, it deals with consistent and complete Co-Design and integrated simulation of IC, package and board in the application context and modular design of 2.5 and 3D integrated systems (re-use, 3D IPs, COTS and supply chain integration, multi-criteria design space exploration for performance, cost, power, reliability, etc...)

Modelling and simulation of heterogeneous systems

The area of modelling and simulation of heterogeneous systems comprises hierarchical Approaches for modelling on System Levels, modelling methods considering operating conditions, statistical scattering and system changes as well as methods and tools for the modelling and integration of heterogeneous subsystems. Furthermore, it deals with methods for HW/SW co-simulation of heterogeneous systems at different abstraction levels, different modelling paradigms, modelling methods and model libraries for learning, adaptive systems and models and model libraries for chemical and biological systems.

Integration of analog and digital design methods

The area of integration of analog and digital design methods comprises metrics for testability and diagnostic efficiency especially for AMS designs, harmonization of methodological approaches and tooling environments for analog, RF and digital design and automation of analog and RF design.

Connecting digital and physical world

The area of connecting digital and physical world comprises advanced simulation methods (environmental modelling, multi-modal simulation, simulation of (digital) functional and

physical effects, emulation and coupling with real hardware, connection of virtual and physical world) and novel More than Moore design methods and tools.

11.3.4. Major Challenge 4: Managing Multiple Constraints

11.3.4.1. VISION

Beyond its pure functionality, different types of properties characterize IC designs. Especially 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. low power consumption, temperature, time, etc.) properties as well as constraints coming from the applications themselves. As a long term vision, we aim at an integrated toolset for managing all relevant constraints.

To manage multiple constraints will require standardization and 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, assessing opportunities to harvest from ambient energy sources to replenish power sources, conditional monitoring of systems for anomalous behaviour of equipment and infrastructure, on-going dynamic functional adaptability to meet application needs, 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.

11.3.4.2. SCOPE AND AMBITION

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 and their application contexts, is an important issue to be considered for system design.

11.3.4.3. HIGH PRIORITY R&D&I AREAS ON MANAGING MULTIPLE CONSTRAINTS

R&D&I activities in this challenge are grouped in three categories (high priority R&D&I areas)

Ultra-Low Power Design methods

The area of Ultra-Low Power Design methods comprises advanced methods for ultra-low-power design, design methods for (autonomous) ultra-low-power systems considering application-specific requirements and methods for comprehensive assessment and optimization of power management and power consumption including the inclusion of parasitic effects.

Efficient modelling, test and analysis for reliable, complex systems considering physical effects and constraints

The area of efficient modelling, test and analysis for reliable, complex systems considering physical effects and constraints comprises hierarchical modelling and early assessment of critical physical effects and properties from SoC down to system level, design and development of error-robust circuits and systems including adaptation strategies, intelligent redundancy concepts, adaptive algorithms. Furthermore it deals with production-related design techniques, consistent methods and new approaches for (multi-level) modelling, analysis, verification and formalization of ECS's operational reliability and service life considering operating conditions and dependencies between hardware and software, detection and evaluation of complex fault failure probabilities. Additionally the area is about a consistent design system able to model and optimize variability, operational reliability yield and system reliability considering dependencies and analysis techniques for new circuit concepts and special operating conditions. Last but not least it comprises advanced test methods, intelligent concepts for test termination, automated metrics/tools for testability and Diagnosis, extraction of diagnostic information and methods and tools for monitoring, diagnostics and error prediction for ECS.

Safe systems with structural variability

The area of safe systems with structural variability comprises architectures, components and design methods and tools for adaptive, expanding systems ((self-)monitoring, diagnostics, update mechanisms, strategies for maintaining functional and data security, life cycle management, adaptive safety and certification concepts, realization of real-time requirements, high availability and functional and IT security, evaluation of non-functional properties, analysis of safety and resilience under variable operating conditions. Furthermore it is about novel simulation approaches for the rapid evaluation of function, safety and reliability and security concepts for adaptive, expanding systems (self-monitoring, environmental analysis, aging-resistant chip identification techniques, ensuring functional safety through robustness guarantee)

11.3.5. Major Challenge 5: Integrating miniaturized features of various technologies and materials into smart components

11.3.5.1. VISION

Smart systems will combine sets of components utilizing features based on nanoelectronics, micro-electro-mechanic, magnetic, photonic, micro-fluidic, acoustic, bio- and chemical principles, radiation and RF as well as completely new technologies in an unprecedented variety. The components will interact with each other as well as with the outside world. The systems will need to be reliable, robust and secure, miniaturized, networked, predictive, able to learn and often shall be autonomous. Physical fabrication and integration of the components will require multitude of materials and process from silicon and non-silicon micro-nano, printing, laminate and other joining and assembling technologies as well as hybrid

combinations of them. The technologies for smart systems, as they are understood here, are fundamental to the properties and capabilities of these components and to the system as a whole. Despite the complexity, manufacturing shall flexibly support large-scale fabrication for the sake of appropriate unit costs.

11.3.5.2. SCOPE AND AMBITION

The SSI industry produces a number of underlying smart technologies (components) such as sensors, actuators, semiconductor technologies, energy generators, storage devices, micro-nano-bio systems (MNBS), MEMS and LAE. After product design and subsequent testing, the orchestra of underlying process technologies leads finally to the integration of smart systems into smart products for enabling smart and sustainable functionalities and services. The components for these integrated smart systems already represent a fusion of functionalities enabled by a set of materials, structural elements, parts or subsystems. The total complexity and diversity exceeds that of the microelectronics components substantially necessitation a tremendous increase in scope and efficiency also of the methods, processes and schemes to be utilized in production, assembly, and test of these various components.

11.3.5.3. HIGH PRIORITY R&D&I AREAS ON COMPONENT LEVEL INTEGRATION

Three high priority R&D&I areas have been identified to master the challenges by improving: i) Functional Features, ii) Materials, and iii) Integration Technologies and Manufacturing

- Further massive increase in the level of complexity and heterogeneity within systems in package (SiP) e.g., by stacking layers of micro-fluidics, MEMS, electronics. communication, and other features, respectively, to form one packaged component
- Artefact free sensors are necessary and are focused on error compensation at the place of origin with innovative solutions (e.g. multi-sensors).
- Innovative solutions are necessary in case of the relevant components regarding long-term stability. The effort for calibration has to be reduced drastically, especially in cases where the new generation of sensors are located inside the monitored processes and where the access by service/maintenance is too cost intensive.
- Coping with the dramatic higher requirements in functional safety and system availability of safety relevant components for the new solutions (automated car, industrial automation, smart energy systems) while keeping the systems affordable to broader public by integrating micro and nano scale detectors for self-monitoring of essential integration features like interfaces (prone to delamination) and joints (risk of cracks).
- Highest volume production of smart power components at minimum cost for the new consumer and industrial products by further advancement of miniaturization. This brings the sensors and signal processing for health monitoring and performance control in closest vicinity to WBG power devices, which can be operated at high temperatures.

For each of these areas, specific actions are noted and put in their timely perspective in section "Timeframes" while with their full text is found in section 12 of the document, "Appendix to Chapter 11".

11.3.6. Major Challenge 6: Providing effective module integration for highly demanding environments

11.3.6.1. VISION

The progress in performance and miniaturization makes electronic systems increasingly attractive and suitable for a direct integration into applications of all fields (chapters 6-11), in which form factor, material behaviour, or cost of the existing solutions have prevented their use so far. For example, motors can be improved into smart drives, which actively adapt to the various use conditions, machine tools can gain precision, efficiency and versatility, automotive systems can take over duties of the human driver, energy or other infrastructure can flexibly adjust to the actual needs, perhaps even by changing from receiver to supplier, exo- and endoskeletons can interact with the patient proactively etc. with the help of smart electronic systems to be added. In summary, the human life will be eased and the societal challenges will be met by the new electronic systems.

11.3.6.2. SCOPE AND AMBITION

In many of the new applications, the electronic systems will be exposed to very demanding conditions. At the same time, the dependence of human life on the safe function of these electronic systems will increase dramatically with these new applicaions. Hence, the future structures of electronics modules will not just show a strong increase in functional and structural complexity but also diversity. They will show yet higher compactness with more features and materials integrated into a given volume. The new structural and fabrication design concepts to be developed will make this possible but need to be able to reliably suppress any unwanted interactions and parasitic effects that may threaten the safe and dependable function of the new modules.

11.3.6.3. HIGH PRIORITY R&D&I AREAS ON BOARD / MODULE LEVEL INTEGRATION

The high priority R&D&I areas identified for the mastering of the challenges in Module Integration are: i) Functional Features, ii) Materials, and iii) Integration Technologies and Manufacturing.

- Fabrication of direct embedding of electronic components and SiPs into substrates/PCBs or even structural components (e.g., motor housing, machine tools like drills, bits, sawing blade, nozzles, …)
- Heat removal from complex and ultra-dense modules comprising power and signal electronics at minimum form factor
- Harsh environment modules operating between -40°C and 300…500°C exposed to vibration and chemicals (moisture, salt dust, gases, oil, …) in addition
- Long-term stable and bio-compatible / implantable micro-fluidics modules

- Fabrication of low-volume customized electronic modules at the process efficiency of high-volume production by implementing new manufacturing technologies based on 3D printing, role-to-role, stamping, injection molding etc.

The specific actions are noted and put in their timely perspective in section “Timeframes” while with their full text can be found in section 12 of the document, “Appendix to Chapter 11” to this chapter.

11.3.7. Major Challenge 7: Increasing compactness and capabilities by functional and physical systems integration

11.3.7.1. VISION

The smart electronic systems will exhibit an increasing level of various kinds of “smartness” - likewise useful in many application fields: healthy living, automotive, communication, energy, water quality, smart textiles, forestry, or food industry. The IoT smart systems will be integrated with existing equipment and infrastructure - often by retrofit. Enabling factors will be: interoperability with existing systems, self- and re-configurability, scalability, ease of deployment, sustainability (e.g. batteries as power source shall rather be replenished by energy harvesting than needing replacement) and reliability, e.g., by self-repair capabilities. Systems of systems, upgradable and automatically configurable suits of sensors may share computer power or -alternatively- will tailor-made fit to the application scenario (sparse, slim and ubiquitous). The smart systems will help industries to cope with the growing variety of production processes and -at the same time- will facilitate individual end-users towards better living.

11.3.7.2. SCOPE AND AMBITION

Many of the new ECS benefit from the same transversal technologies. Advanced driver assistance systems and minimal invasive surgery devices are both requiring heterogeneous (3D) integration of different building blocks. Similarly, intraocular measurement devices and environmental sensors for dangerous substances both rely on wireless communication for data exchange. Also, there is the general trend for sensors and actuators to go much closer position to the actual scene in order to in-situ measured data. Hence, harsh environments with high temperature, humidity, vibration, electrical fields must often be endured (ultra-)long, e.g., for 15 … 30 years, with zero defect and without artefacts beyond the processes. In case of human health monitoring (hyperpiesia, diabetes, stroke, infarct), the much smarter sensor solutions will increasingly need to be based non-invasive principles. In all cases, highest quality raw sensor signals with high reproducibility need to be provided by the next generation of innovative sensors under the condition of extreme miniaturization, lowest power consumption, and mass production. On top, smart systems for collaborative environments as well as driver assistance systems require autonomous decision-making capabilities to enable efficient interaction.

For the sake of European R&D&I efficiency, these common challenges shall be addressed by application independent developments of system and application level integration technologies

11.3.7.3. HIGH PRIORITY R&D&I AREAS ON SYSTEM & APPLICATION LEVEL INTEGRATION

Again, the main R&D&I activities identified are: i) Functional Features, ii) Materials and iii) Integration Technologies and Manufacturing; detailed actions are listed under "Timeframes" and in section 12 of the document, "Appendix to Chapter 11".

- Manage highly compact heterogeneous architectures for new smart electronic systems in safety relevant applications and various demanding environments (harsh, in vivio, …)
- Master the HW + SW integration & testing for the systems of much higher complexity at that level of comprehensiveness and efficiency at the same time, which is needed for high volume consumer and industrial products (automated car, production robots, …)
- Coping with the high requirements on functional safety and availability of the new applications for complex systems comprising several modules with heterogeneously integrated components, i.e., implementing efficient and safe health monitoring for systems with many different critical elements and a multitude of likewise probable failure modes

11.4. Expected achievements

Overcoming the challenges in section 3 will enable European Industry to maintain and increase its leading position in developing, producing and selling future Electronic Components and Systems that meet societal needs in a way that is cost efficient, yet yields products of highest quality. Especially, expected achievements are

- the creation, respectively extension of modelling and specification techniques and languages matching the new properties of and requirements for critical, autonomous, cooperating, and evolvable systems, developing and standardization of architectural measures to ease their validation and test, appropriate V&V and Test methodologies to ensure their expected and needed qualities.
- the establishment of standard languages and ontologies and associated tools and methods to develop system models that can be shared across the system design value chain.
- the establishment of standard languages, plus associated tools and methods, to build integrated design flows and platforms targeting heterogeneous SoC and SiP.
- the establishment of common platforms and libraries of parts/components, that enable modular development, reusable IP, standardized software and middleware solutions, etc.
- enabling systematic re-use of (models of) components, environments, contexts, etc.
- a drastic increase in the scalability of methods to match the increased complexity of systems.

- improved capabilities to develop, validate, and optimize system properties and qualities (from power consumption, functional and non-functional systems properties like safety, security, reliability, real time).
- methods and tools to facilitate online monitoring and diagnostics with embedded context awareness.

The general strategic actions required are:

- Demand – individual manufacturing, personalised (medicine, smart home, smart transportation und smart environments)
- Shortening the time-to-market – from research and testing until production
- Automation of fabrication processes for smart devices
- Creating open-innovation platforms towards enabling easier cooperation of stakeholders
- Securing R&D&I financing in a complex ecosystem (regarding SMEs)
- 'Deploy and forget' retrofitability – self-sustaining IoT devices requiring no maintenance

11.5. Make it happen

Design Ecosystem: Key success factor of this roadmap is the actual adoption by the European Industry of the new methodologies in Systems and Component Engineering. This implies not only traditional technology transfer but also changes in the way of working in industry towards a much more comprehensive structured approach. This implies that co-operation with and between the leading industries in Europe is of very high importance.

Many of the R&D&I topics described in the previous chapters cannot be solved by a single company or organisation. Most noteworthy, this includes all standardisation and pre-standardization activities, but also

- the development of a common design and validation methodology applicable along the value chain, that is
  - accepted by public authorities, especially by certification authorities
  - accepted by the general public in terms of yielding trustworthy products
  - based upon a V&V and Test methodology using standardized catalogues of system contexts/scenarios as test cases
  - enabling cost-efficient processes and allows re-use and re-certification.
- support for validation of methodologies in industrial practice
- support for industry in the process of adopting new methodologies
- support for heterogeneous applications addressing yield, heat, and mechanical stress in a more holistic way.

Therefore, a seamless, open, sustainable and extendable design ecosystem for processes, methods and tools for the cost efficient design is needed, focusing on design technologies based on standards. It has to start at system level and has to contain flexible, seamless design flows for

all design domains and heterogeneous subsystems to (co-)design ECS with and for sophisticated feature-rich innovative products of superior performance and quality.

The creation of such an ecosystem, involving all stakeholders along the value chain, is a key success factor for European industry to maintain their leading role in Engineering ECS.

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

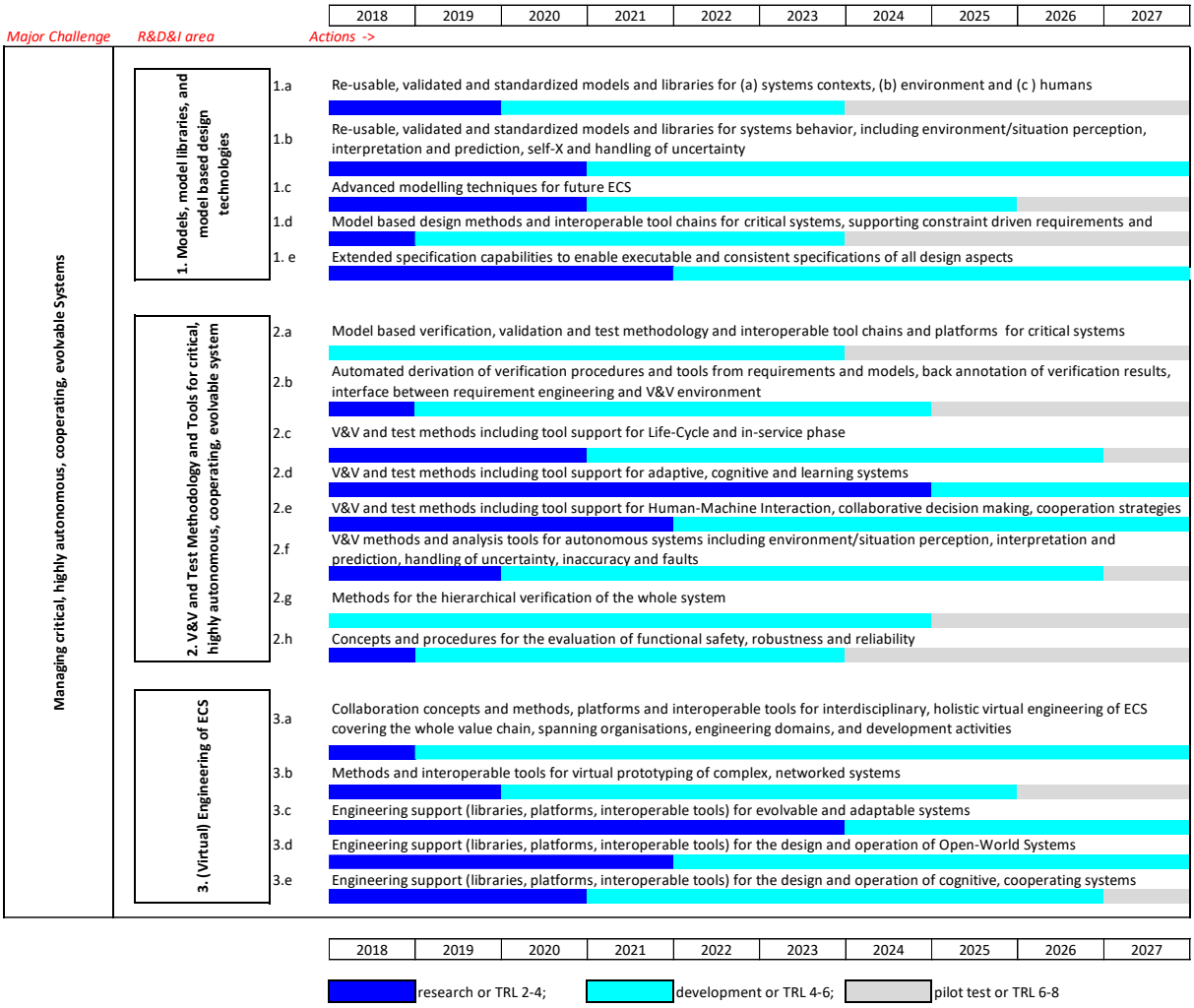
When speaking about the smart systems ecosystem in Europe, which, as described, is versatile in many respects, it is essential to develop new forms of stakeholder cooperation towards market-ready products. Herewith, a special impact is expected for SMEs and start-ups to maintain or increase their presence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

11.6. Timeframes

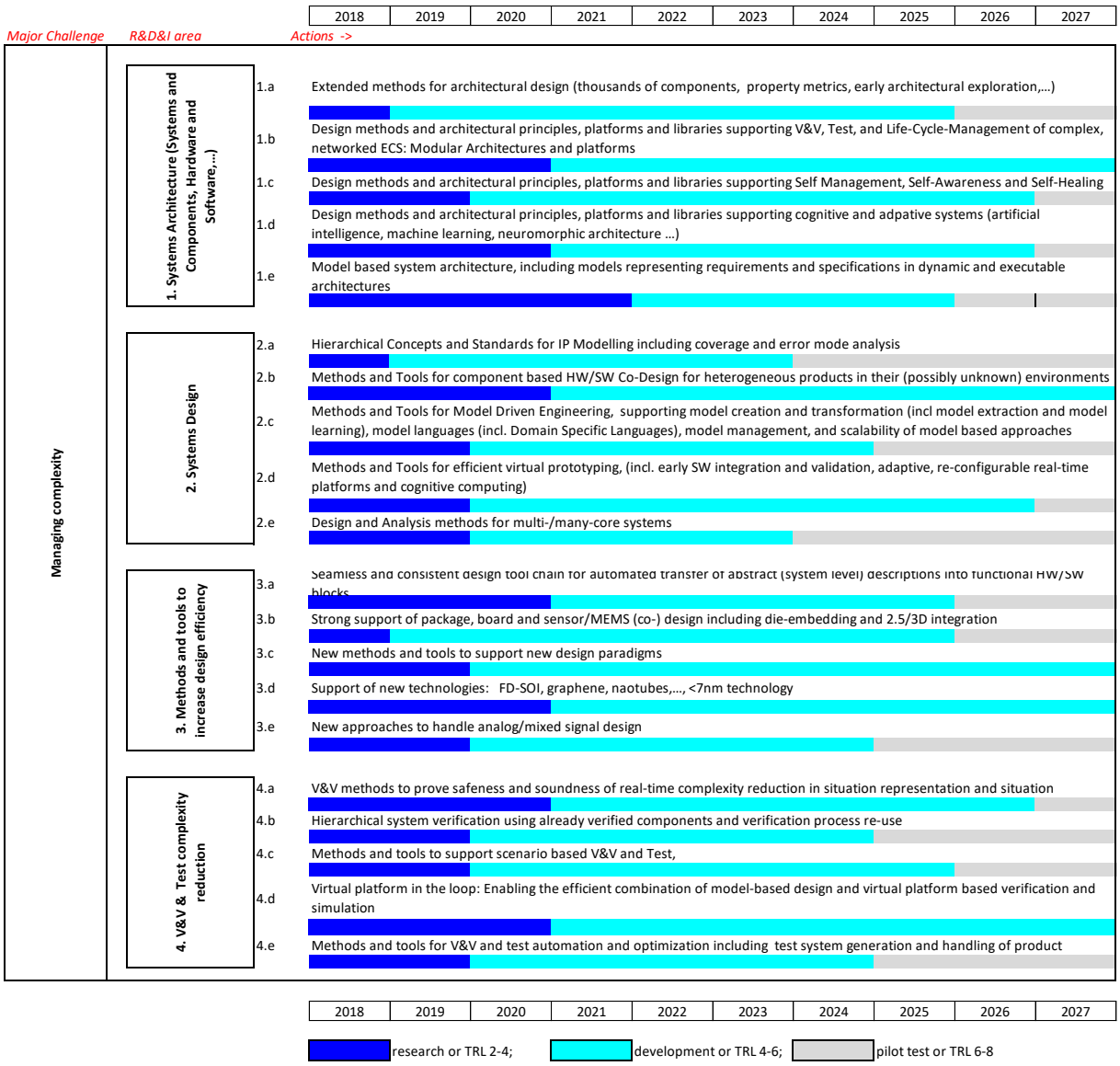
The timeframes given in this section denote for each R&D&I activity (topic) in each high priority R&D&I area the foreseen development lines. Each timeline is divided in three parts, for producing results of TRL2-4, 4-6, and 6-8 respectively. The concrete meaning of this section is that we envisage in a given year projects producing results of this TRL level or higher to be started (c.f. Section 0.6.2).

The Topics (actions) are abbreviated if necessary and therefore also listed, with full description, in section 12 of the document, "Appendix to Chapter 11".

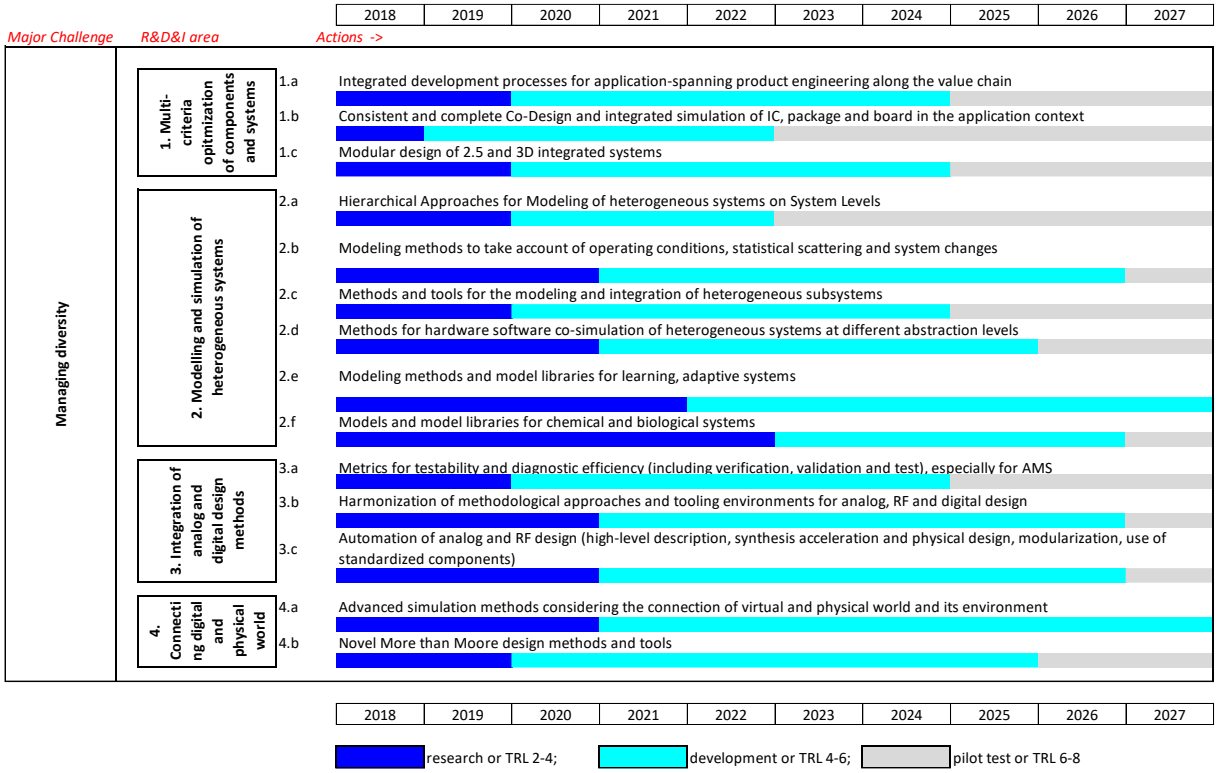
Managing critical, autonomous, cooperating, evolvable systems



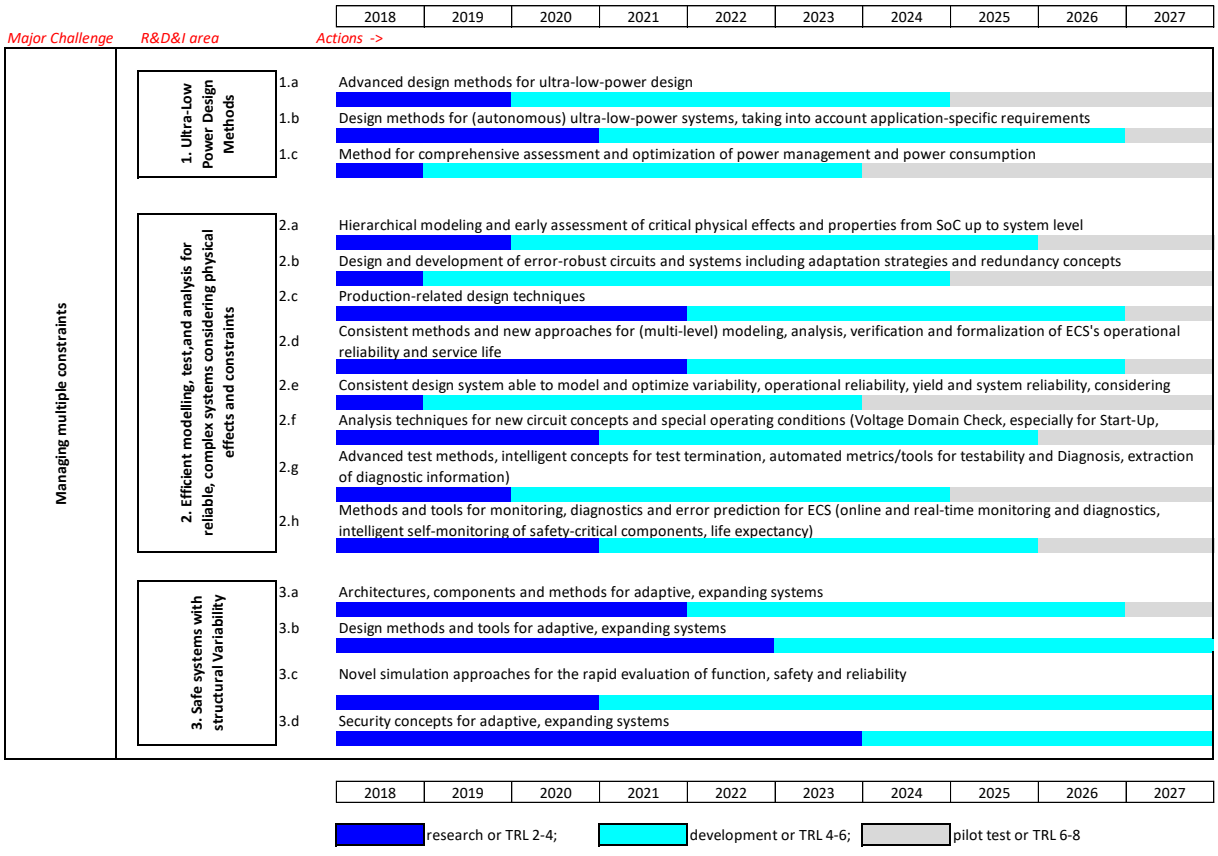
Managing Complexity:



Managing Diversity:

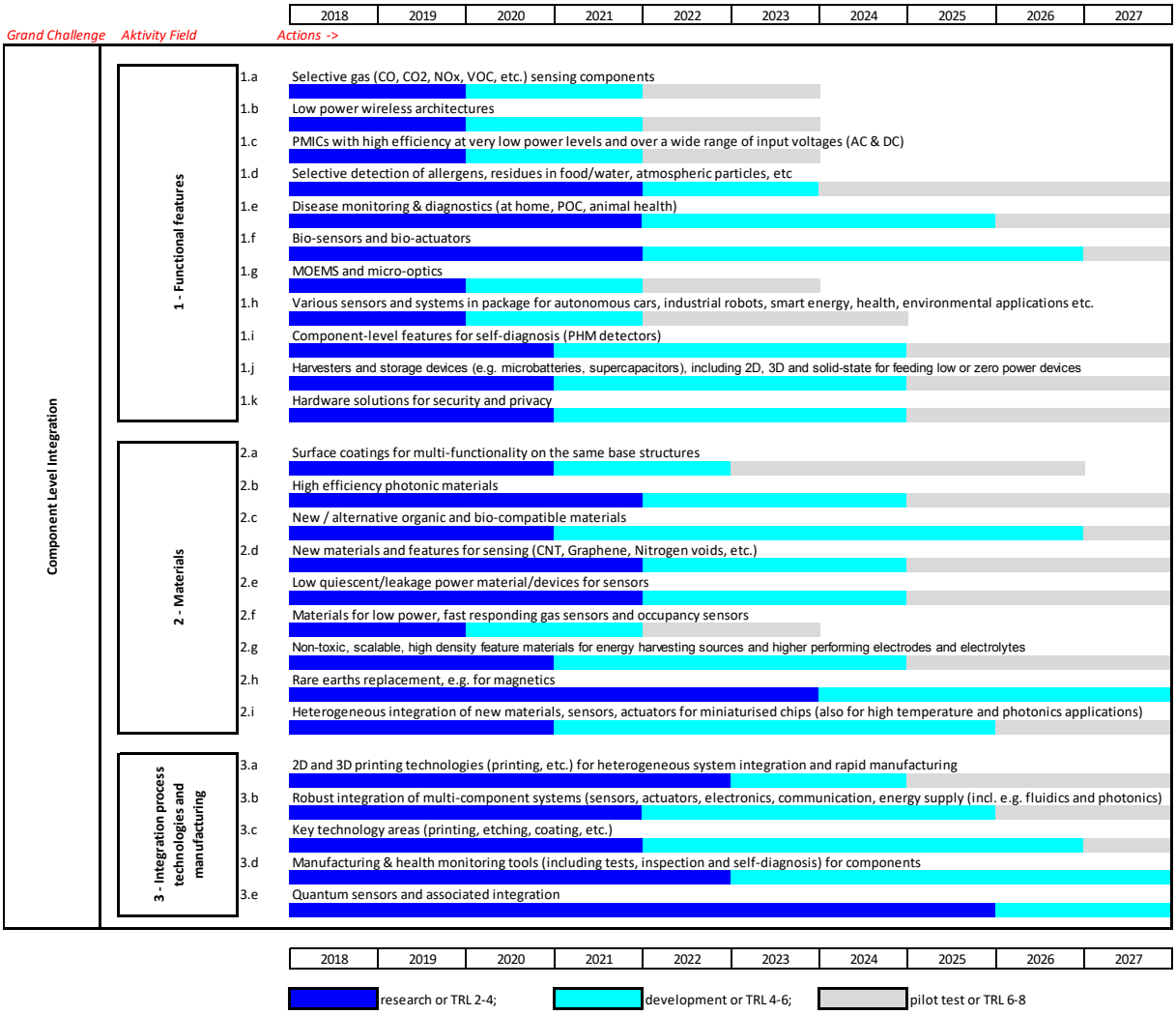


Managing Multiple Constraints:



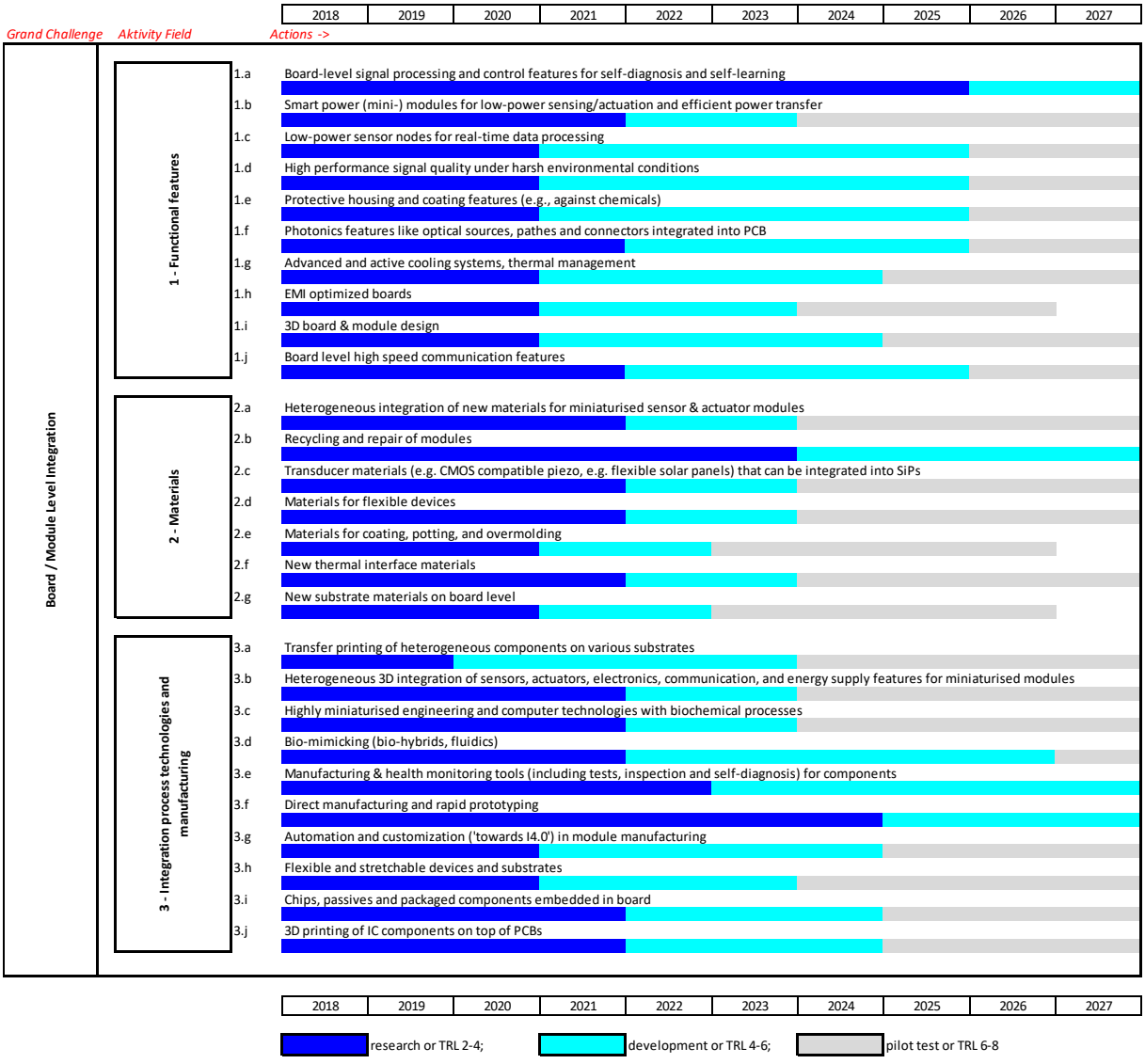
Component Level Integration:

Integrating miniaturized features of various technologies and materials into smart components



Board / Module Level Integration:

Providing effective module integration for highly demanding environments



System & Application Level Integration:

Increasing compactness and capabilities by functional and physical systems integration

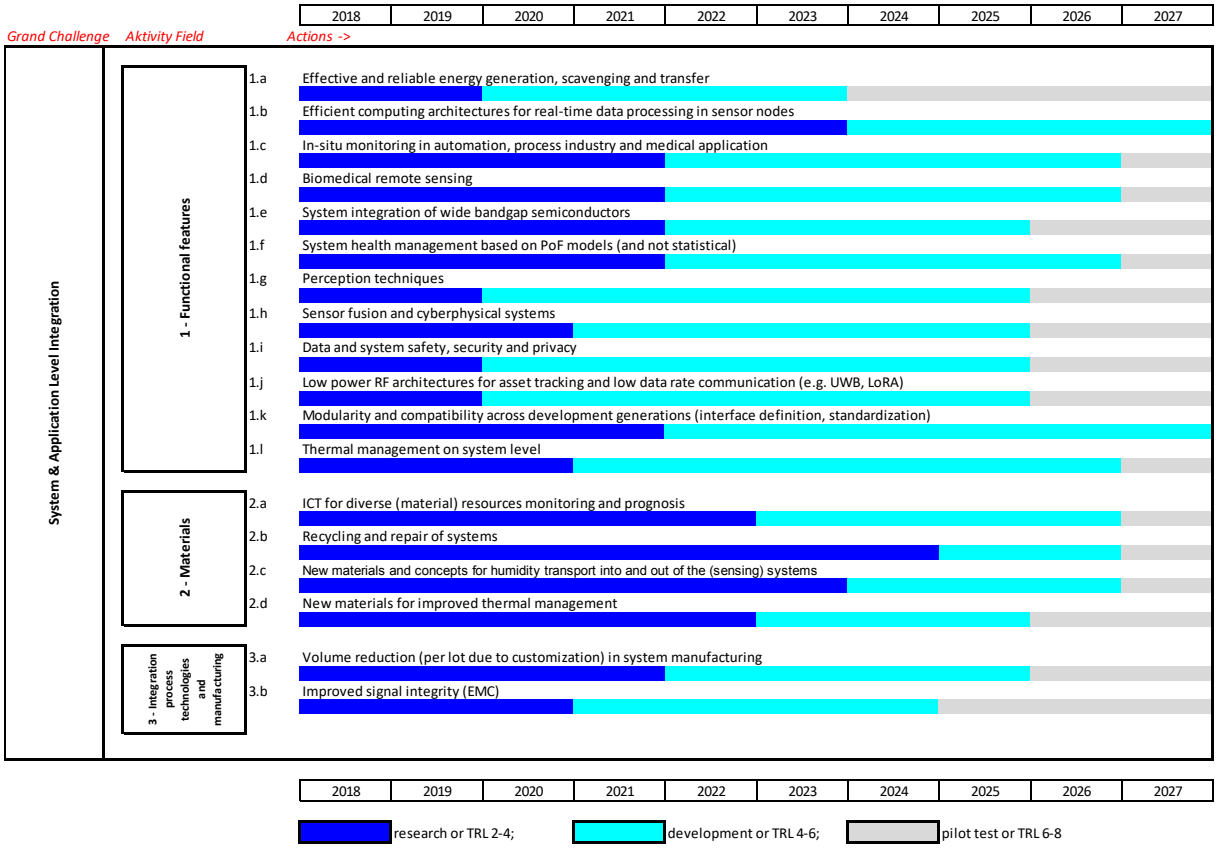


Figure 28 - Timelines

11.7. Synergies with other themes

For the Architecture, Design and Integration Technologies described in this chapter we expect a huge potential for synergies with R&D&I Topics outlined in all other chapters. New and advanced applications described in Chapter 6 to 11 will give raise to further advances in design and integration technologies. We expect most R&D projects based on this SRA to result in innovations in applications as well as in accompanying design and integration technologies.

There is a strong link between the V&V and Test methods and tools described here and the techniques described in Chapter 13 on Safe and Secure Systems. Computing and storage nodes (Chapter 14) are essential components in most ECS systems; R&D&I topics to advance these nodes therefore strongly interact with the platform and Systems Design topics here. Connectivity and interoperability research (Chapter 12). Last, but not least, the Process, Technology and Materials Chapter 15 is of huge importance here.

The field of Physical and Functional Systems Integration 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 ECS SRA, the field benefits

from links to all other technology chapters. 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, Energy in buildings and micro-grids, Environment and Climate Action, Security, eHealth and wearables, transportation and food and water supplies.

DRAFT

12. Connectivity and Interoperability

Executive Summary

Mobility being everywhere, connectivity and interoperability are today key enablers to support the development of innovative application in various markets (consumer, automotive, digital manufacturing, network infrastructure …). The ubiquitous availability of smart phones and 4G wireless networks is of course a good example (one can have in mind the associated booming development of apps), but the availability of new innovative connectivity technologies (IoT, 5G, car to car, …) enables to envision a wide range of enhanced and new business opportunities for the European industry (smart cities, autonomous driving, …).

To support this vision, smart, secure and user-friendly connectivity solution are necessary in order to ensure citizen privacy and reach a broad acceptance from consumer. Clearly, the main objective of this chapter is to enable the seamless integration of various technologies (hardware and software) in order to develop complex connected system in an effective manner. To do so, semantic interoperability and heterogeneous integration are key game changers.

12.1. Relevance

12.1.1. Competitive Value

While connectivity is today needed in almost all application field (consumer market, automotive, health, wellbeing, smart cities …), we can note that European players are stronger on Internet of Things (IoT) and secured solution (with hardware leaders such as NXP or STMicroelectronics, solution providers such as GEMALTO and service provider such as SIGFOX). On the other hand, mass market oriented businesses such as smart phone is today dominated by US (Qualcomm, Avago, etc...) or Asian players (Huawei, Murata, etc…) with European ones being focus on system integration, digitalisation, analytics, sensor/actuators (Siemens, ABB, Ericsson, Danfoss, Thales, Philips, BMW, Daimler, Bosch, STMicroelectronics, etc…).

Consequently, in order to strengthen Europe position and enable European industry to capture new business opportunity associated to the connected world we live in, it is of vital importance to support Europe technological leadership on the connectivity topic supporting digitalisation based on IoT and System of Systems (SoS) technologies (for example by being at the for front of new standard development as it is done for current 5G initiative). Moreover, in order to bring added value and differentiation in comparison with US and Asian competitors European industry has to secure the access to any innovative hardware or software technology enabling the development of complex connected systems (which will help to capture more value by targeting higher end or more innovative applications).

To illustrate the competitive value for Europe of connectivity and interoperability topics, we can quickly review a few challenges associated to connectivity requirement on market where Europe industry is historically strong or has to secure its position for strategic reasons:

DRAFT

- **Automotive**: The main driver is here the deployment of Advanced Driver Assistance Systems (ADAS), which is a key opportunity for European semiconductor companies. While ADAS market today generates moderate revenue (less than $2 billion in 2015), compared with $29 billion for automotive electronic systems, this market is expected to grow rapidly. Industry experts expect to see an annual increase of more than 10 percent from 2015 to 2020. This could make ADAS one of the highest growth rates in the automotive sector and related industries. Moreover, it is likely that regulators will require vehicles to be equipped with certain ADAS applications over the next five years. For example, key automotive markets like Europe, Japan and North America are in the process of introducing legislation to aid the prevention of fatalities of vulnerable road users, with emphasis on the use of vision systems. This trend is driving the quick adoption of ADAS using cameras by car makers around the world. Trend which will be reinforced by the development of autonomous driving technology (such as Tesla Autopilot technology). Connectivity technology is consequently a major challenge since inter-sensor communication requires high bandwidth, innovative solutions will be necessary to prevent network overloads. A broadband network with hierarchical architectures will be needed to communicate with all the function domain of the car in a reliable way.

- **Digital Production**: Production of gods and services already involves a multitude of data obtained from various sources. Digitalisation is calling for a drastic increase of data sources ranging e.g sensors, simulators, models. Such data will be used for control, analytics, prediction, business logics etc. having receivers like, e.g. actuators, decision makers, sales, and customers. Obviously this will involve a huge number of devices with software systems that are required to interoperable and possible to integrate for desired combined functionality. This calls for seamless and autonomous interoperability between involved devices and systems regardless of chosen technology.

  Europe is the world leading region for production and manufacturing automation thanks to companies like Siemens, ABB, Schneider, Metso/Valmet, etc. The industrial control and manufacturing automation is projected to reach USD 153.30 Billion by 2022, at a CAGR of 4.88% [Markets and Markets, 2016]. To this the MES and ERP markets should be added . The cloud ERP market size is estimated to grow from USD 18.52 Billion in 2016 to USD 29.84 Billion by 2021, at an estimated Compound Annual Growth Rate (CAGR) of 10.0% [Markets and Markets, 2016]. The Manufacturing Execution System (MES) market was valued at USD 7.63 Billion in 2015 and is expected to reach USD 18.22 Billion by 2022, at a CAGR of 13.6% [Market and Market 2016]. The factors that are driving the growth of these markets include low deployment cost, increasing use of industrial automation, adoption of MES and ERP owing to growing benefits, and importance of regulatory compliance. To this should be added the expected impact of

DRAFT

Industry4.0 and its use of IoT and SoS technologies, most likely to occur after 2022. Numbers estimated by companies like Cisco and Ericsson forecasts very high number of IoT devices that will be used in development of digital production. It's clear that software to a very large extent and electronics hardware contributes to this market.

- **Data Centre**: In order to make 5G a reality, telecommunication operator and big internet company such as Google, Apple, Facebook or Amazon will have to increase the size of their data centre in order to cope up with users demand for more data. Due to the complexity of the mega data centres deploy today this create a huge interconnect challenge. Considering currently deployed data centre such as Google ones, people generally have in mind optical fibre interconnect solution. Optical fibre is a key technology for high speed links (> 25 Gb/s) but there is in fact a lot of copper cable in data centres deploy these days. "We see copper as maybe not the principal but one of the main interconnects used inside the rack at 100GbE," says Mellanox senior director for marketing, Arlon Martin, who believes an 8m length could be enough to satisfy 98 percent of in-rack cabling requirements. The drawback of this approach is that each copper cable consumes more than 1 W. Having in mind that the biggest data centre currently deployed can have more than 400 000 servers, this means that big data centre can consume 400 kW/h just to connect the servers to each other. To put this number in perspective, the average power consumption of a house in Europe is 6 kW/h. Consequently, if we can develop an innovative cost effective, power efficient (~100 mW) and high speed (at least 10 Gb/s) cable technology able to work up to 10 m, we will also open new business opportunities from the telecommunication infrastructure side by enabling greener services.

12.1.2. Societal benefits

Beyond their economical impact, connectivity and interoperability are also expected to play a key role in many societal challenges to be faced in next decades. As it will be illustrated below, the societal benefits associated with connectivity are then key assets in order to improve European citizen living standard and maintain Europe leadership.

- Education improvement: The internet plays a pivotal role in extending access to educational resources and in accelerating knowledge sharing. The internet makes learning resources available to students and teachers; it allows learning and consultation online and can be a valuable complement to the classroom experience. The potential exists for students anywhere to have access to online educational eBooks, tests and courses. These resources can substitute traditional textbooks which may not be readily available or are prohibitively expensive in developing countries. Connectivity has then the potential to significantly extend the impacts of the internet in increasing quality of education (reliable access, improved student experience …) and ultimately academic proficiency, attainment levels and employment outcomes. Improved educational outcomes can have a strong positive impact on individuals' income and health outcomes as well as on the economy. Importantly, in addition to these effects, technology can

DRAFT

expand opportunities for students to engage in collaborative learning, with great potential for learning and circulation of ideas.

- Healthcare improvement: Connectivity has the potential to improve medical behaviours for patients and healthcare professionals as well as the delivery of improved medical service. Connected devices can transform the way healthcare professionals operate by allowing remote diagnosis and more efficient ways of treatment. For example, patient information could be sent to hospitals via mobile and internet applications, thus saving travel time and service costs and substantially improving access to healthcare, especially for rural populations. Connectivity and associated devices and services could complement and improve existing medical facilities. From citizen side, monitoring of illnesses can also be enhanced by mobile and internet applications designed to remind patients of their treatments and control the distribution of medicine stocks.
- Energy and environment: One of the projected impacts of digitalisation is better abilities to optimise energy utilisation and minimise environmental footprints. Connectivity and Interoperability are here critical parts of ICT infrastructure that is essential to allow such optimisation and minimisation. Energy efficiency market is estimated to $221B in 2015 which is 14% of the global energy supply investments [IEA 2016B]divided between buildings (53%) transport (29%) and industry (18%) [IEA, 2016A].
- Improve public services, social cohesion and digital inclusion: ICT technologies have long been recognised for promoting and facilitating social inclusion, i.e. the participation of individuals and groups in society's political, economic and societal processes. One way in which ICT technologies expand inclusion is through effective public services that rely on ICT infrastructure and through digital inclusion, i.e. the ability of people to use technology. These three aspects are deeply intertwined, and they span dimensions as diverse as disaster relief, food security, and the environment, as well as citizenship, community cohesion, self-expression and equality. Public authorities can enhance disaster relief efforts by promoting the spread of information online and by implementing early-warning systems. The internet also enables relief efforts through crowd-sourcing: during Typhoon Haiyan in the Philippines, victims, witnesses and aid workers used the web to generate interactive catastrophe maps through free and downloadable software, helping disseminate information and reduce the vulnerability of people affected by the disaster. Communities can also be strengthened by connectivity, thereby promoting the inclusion of marginalised groups.

Europe should recognise the importance of connectivity in complementing the delivery of healthcare, education and other social services and should promote investment in the development of innovative connectivity solution targeting this topics in order to improve European citizen day to day life.

DRAFT

12.2. Major Challenges

The connectivity and interoperability technology focus enabling the projected commercial and societal benefits are related to the OSI model layer 1,4,5 and 6.

12.2.1. Major Challenge 1: Meeting future connectivity requirements leveraging heterogeneous technologies

12.2.1.1. VISION

Targeting system and application, we have to consider the interconnection between sub-systems and should focus on individual component technology development according to needs identified at system or application level. To support this system vision, the promotion of innovative technology enabling heterogeneous integration is a key point.

Heterogeneous Integration refers to the integration of separately manufactured components into a higher-level assembly that in the aggregate provides enhanced functionality and improved operating characteristics. In this definition components should be taken to mean any unit whether individual die, device, component and assembly or sub-system that are integrated into a single system. The operating characteristics should also be taken in its broadest meaning including characteristics such as system level cost-of-ownership.

This is especially true from hardware side in the context of the end of Moore law. It is the interconnection of the transistors and other components in the IC, in the package, on the printed circuit board and at the system and global network level, where the future limitations in performance, power, latency and cost reside. Overcoming these limitations will require heterogeneous integration of different materials, different devices (logic, memory, sensors, RF, analog, etc…) and different technologies (electronics, photonics, MEMS and sensors).

12.2.1.2. SCOPE AND AMBITION

This major challenge scope involves to fully leverage Europe existing semiconductor manufacturing strength and especially the availability of derivative semiconductor process (BiCMOS, Si Photonics, RF SOI, FDSOI, GaAn …). The ambition is to develop innovative connectivity solution (for example investigating new frequency band or medium to propagate the signal) and strengthen Europe leadership on 5G and IoT markets.

DRAFT

OSI Model			
Layer		Protocol data unit (PDU)	Function[3]
Host layers	7. Application		High-level APIs, including resource sharing, remote file access
	6. Presentation	Data	Translation of data between a networking service and an application; including character encoding, data compression and encryption/decryption
	5. Session		Managing communication sessions, i.e. continuous exchange of information in the form of multiple back-and-forth transmissions between two nodes
	4. Transport	Segment (TCP) / Datagram (UDP)	Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing
Media layers	3. Network	Packet	Structuring and managing a multi-node network, including addressing, routing and traffic control
	2. Data link	Frame	Reliable transmission of data frames between two nodes connected by a physical layer
	1. Physical	Bit	Transmission and reception of raw bit streams over a physical medium

Figure 29 - The focus for connectivity and interoperability R&D&I are related to the OSI model layers 1,4,5 and 6

Envisioned innovative connectivity solution should drive the development in Europe of innovative packaging, MID and printed circuit technologies (by providing system requirements and then facilitating the specification of required technologies) in order to enable the development of differentiated and higher value connectivity system leveraging heterogeneous integration scheme.

12.2.1.3. COMPETITIVE SITUATION AND GAME CHANGERS

While Europe has a very clear technology lead in derivative semiconductor technology, we can note that most of the end users developing the final connectivity system are based While Europe has a very clear technology lead in derivative semiconductor technology, we can note that most of the end users developing the final connectivity system are based either in Asia or in the US. We can have for example in mind that Europe is strong on RF SOI (STMicroelectronics, SOITEC, etc...) and BiCMOS (Infineon NXP, STMicroelectronics, etc...) while the module makers capturing the main part of the value associated to 4G Front End Module are based in the US (Avago, Qorvo, Skyworks, etc...) or in Asia (Murata, Huawei, etc...).

In order to enable the emergence of European champion delivering connectivity module/solution, the key game changer will consist in the enablement of the necessary ecosystem required to develop innovative connectivity system leveraging both heterogeneous integration scheme and derivative semiconductor process already available in Europe.High priority R&D&I areas

The high priority technical and scientific challenges are:

- 5G technologies from IoT to backend (HW, control, envelope tracking, system integration …)
- Evaluation of new frequency band (5G, > 100 GHz ...)
- Evaluation of new medium (RF/mmW signal propagation over plastic, single mode optical waveguide using laminated polymer platform ...)

- Enablement of a European ecosystem able to support heterogeneous integration (multi die System in Package, advanced assembly capability, advanced substrate manufacturing ...)

12.2.1.4. EXPECTED ACHIEVEMENTS

- Innovative connectivity technology working in new frequency band and achieved using Europe derivative technologies (RF SOI, BiCMOS, GaN …)
- Innovative connectivity solution using new medium
- Highly integrated connectivity module/system heterogeneously integrating Europe derivative technologies

12.2.2. Major Challenge 2: Enabling nearly lossless interoperability across protocols, encodings and semantics

12.2.2.1. VISION

To fully leverage this heterogeneous integration at hardware level, software interoperability is the parallell challenge in order to provide connectivity that will allow for System of Systems (SoS) integration connectivity from IoT to backend systems, enabling usage of thus available data for application on digital production, automotive, data centers, healthcare, energy usage optimisation and minimisation of environmental impact. Thus an alterantive expression of the major challenge is: Enabling SoS integration through nearly lossless interoperability across protocols, encodings and semantics. To do so, dedicated software tools, reference architecture and standardisation are key topics in order to support SoS integration. Thus enabling the provision of scalable and evolvable System of Systems.

12.2.2.2. SCOPE AND AMBITION

This grand challenge scope involves interoperability of service or agent protocols including encoding and semantics. Where semantics interoperability is a specific focus. Leading to architectures, technologies and engineering tools supporting integration of SoS for highlighted application areas at design time and run time.

The ambition is technology that enables nearly lossless interoperability across protocols, encodings and semantics while providing technology and engineering support foundations for low cost integration of very complex and evolvable SoS.

12.2.2.3. COMPETITIVE SITUATION AND GAME CHANGERS

Europe has a very clear technology lead in automation technology in general. The next generation of automation technology is now pushed by Industri4.0 initiatives backed by EC and individual countries. In automative the autonomous car vision is the driver. Here Europe has a strong competitive position. Robust and dependable connectivity and

DRAFT

interoperability is here fundamental for market success. In healthcare the ageing population is the driver. Europes position is good but scattered.

To maintain and strengthen the European lead advancements in interoperability, integrability and associated engineering tools is necessary. The game changers are:

- IoT interoperability, SoS integration technology and engineering tools reducing connectivity developments cost by 80%
- Open interoperability and integration frameworks and platforms.
- Ease of integration of new and secure IoT hardware and radio solutions like 5G.

12.2.2.4. HIGH PRIORITY R&D&I AREAS

The high priority technical and scientific challenges in both design time and run time are:

- Semantics interoperability
- Autonomous translation of protocols, encodings and semantics.
- Enabling of IoT and SoS evolvability over time and technology generations
- Integration with security aspects of Major Challenge 3, see below.

12.2.2.5. EXPECTED ACHIEVEMENTS

- Reference architectures with implementations enabling evolvability and autonomous behaviour
- Autonomous translation across protocol, encodings and semantics
- Architecture implementations with performance that meets critical performance requirements in focused application areas

12.2.3. Major Challenge 3: Ensuring Secure Connectivity and Interoperability

12.2.3.1. VISION

Data protection has to be ensured at an appropriate level for each user and functionality regardless of technology. Thus an alternative formulation of the major challenge is: Ensuring Security interoperability across any Connectivity. This foresees the usage of different technologies in connectivity networks. Technology differences imposes security incompatibilities leading to increased engineering costs. Therefore development of innovative hardware and software security solution is of fundamental importance. Such a solution will have to be linked with the challenges 1 and 2 in order to ease SoS engineering, deployment and operation in a seamless manner.

12.2.3.2. SCOPE AND AMBITION

The scope is to enable connectivity chains and networks that goes from hardware over software to system of systems where appropriate security can be engineered and enabled in both design time and run time. The ambition is that such connectivity chains and networks can be engineered at 20% of current costs.

DRAFT

12.2.3.3. COMPETITIVE SITUATION AND GAME CHANGERS

It's clear that US is the security leader when it comes to computer connectivity. The big potential game changer is here 5G where Europe has a leading role.

To advance the European position flexible security integration with 5G connectivity to European strongholds like automation and automotive seams of vital importance.

The game changers are:

- Flexible and adaptable IoT and SoS connectivity security technology and engineering tools reducing security deployment, operations and maintenance cost by 40%
- Open security and integration frameworks and platforms.

12.2.3.4. HIGH PRIORITY R&D&I AREAS

The high priority technical and scientific challenges are:

- Security semantics
- Autonomous security translation in connectivity chains and networks
- Enabling of IoT and SoS security evolvability over time and technology generations

12.2.3.5. EXPECTED ACHIEVEMENTS

- Open implementation of reference architectures supporting security evolvability and autonomous behaviour
- Tools and technology supporting autonomous security translation in connectivity chains and networks
- Architecture reference implementations with performance that meets critical performance requirements in focused application areas

12.3. Make it happen

Providing the connectivity and interoperability requested by applications a transition from always best connected to always best integrated is necessary. For the purpose interoperability at all layers in the ISO communication stack is necessary. For example at the application level machine understanding of data semantics is of vital importance to reduce engineering costs. At the physical level hardware supported payload transfer from e.g. 5G to/from Ethernet will reduce security issues compared to software supported transfer.

This calls for substantial standardisation efforts having both a international perspective and a technology HW/SW perspective.

The availability of engineers having interoperability and dynamic integration competences is currently limited mainly due to limited academic research and education towards SoS problems. Thus joint industrial and academic efforts to rapidly increase the availability of such competence is of vital importance.

DRAFT

12.4. Timeframes

The anticipated time line for finding solutions and mature implementations to the stated major challenges is depicted in the table below.

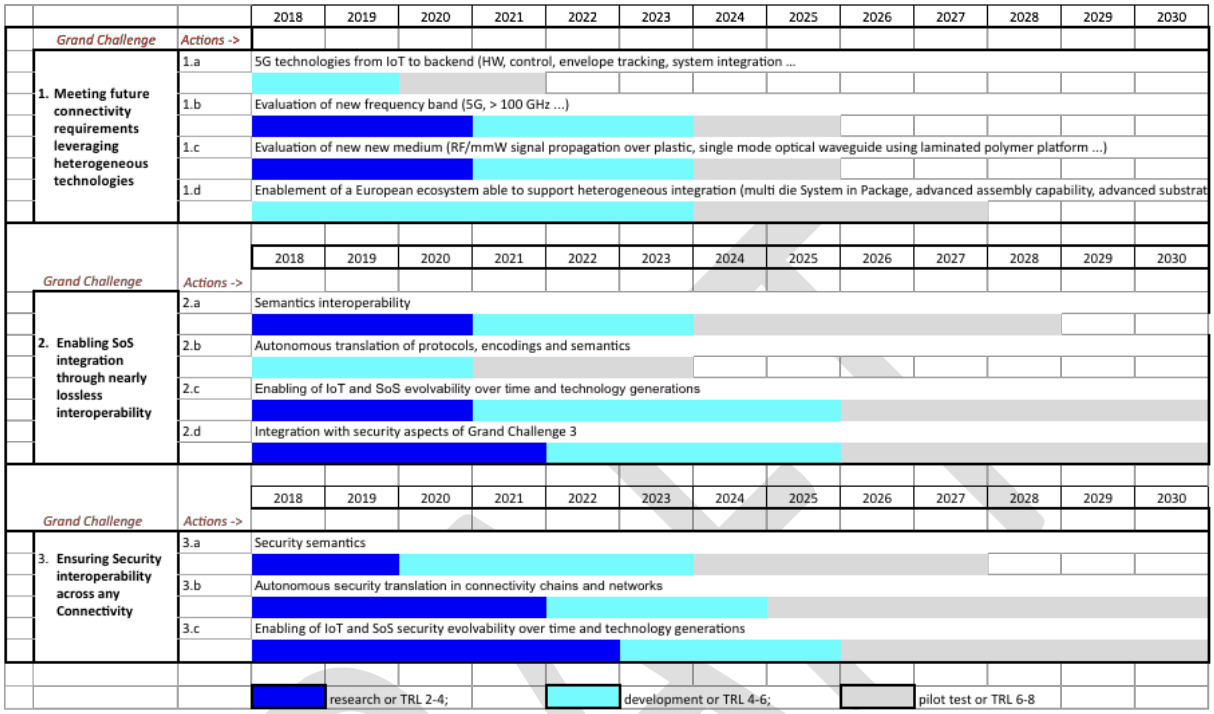


Figure 30 - Connectivity and Inetroperability timeline

12.5. Synergies with other themes

Interoperability and connectivity provides foundation properties for all targeted application areas, Ch1-Ch5. There is also a close relation ship to Ch 4 where interoperability and connectivity also provides a foundation for the CPS systems and engineering aspects of Ch6. The specific problem of security interoperability and coexistence and translation between different security technologies is an area with strong synergies to Ch8.

DRAFT

13. Safety, Security and Reliability

13.1. Executive Summary

Safety, security and reliability are fundamental components of any innovation in the digital economy. Novel products and services such as personal healthcare monitoring, connected cars or smart homes will bring strong benefits to our society only if users are assured that they can depend on and trust them, especially for artificial intelligence (AI) based systems.
Safety and security, as well as dependability engineering, require the consistent merge of different engineering disciplines, leading to heterogeneous and possibly contradictory requirements. Dependability in its full meaning includes system properties like availability, resilience, survivability, adaptability, maintainability and so forth. This chapter introduces and describes four Major Challenges that have been identified for the European Research and Development community over the next five years in the area of "Dependability and Trustability". It covers all aspects to build trustable technology, either by measures against technical faults (safety, reliability) or with protection against malicious or unintended human intervention (security) and the related use of personal data (privacy).

The Major Challenges in Safety, Security and Reliability are:

1. Safety, security and privacy by design
2. Reliability and Functional Safety
3. Secure, safe and trustable connectivity and infrastructure
4. Privacy, data protection and human interaction.

13.2. Relevance

13.2.1. Competitive Value

Since safety, reliability, privacy and security are mandatory items to be considered in many sectors where Europe has leadership or a significant position, European Industrial competitiveness will be driven by a growth of safety & security revenues in the European market (500 million of habitants) but also a re-enforcement of European companies' position and market share in this domain.

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

According to Gartner [1] worldwide spending on information security products and services will reach $86.4 billion in 2017, an increase of 7 percent over 2016, with spending expected to grow to $93 billion in 2018. A good example is cybersecurity for automotive. According to IHS [2] this market will reach 753M$ in 2023 with variable growth according to the segment.

DRAFT

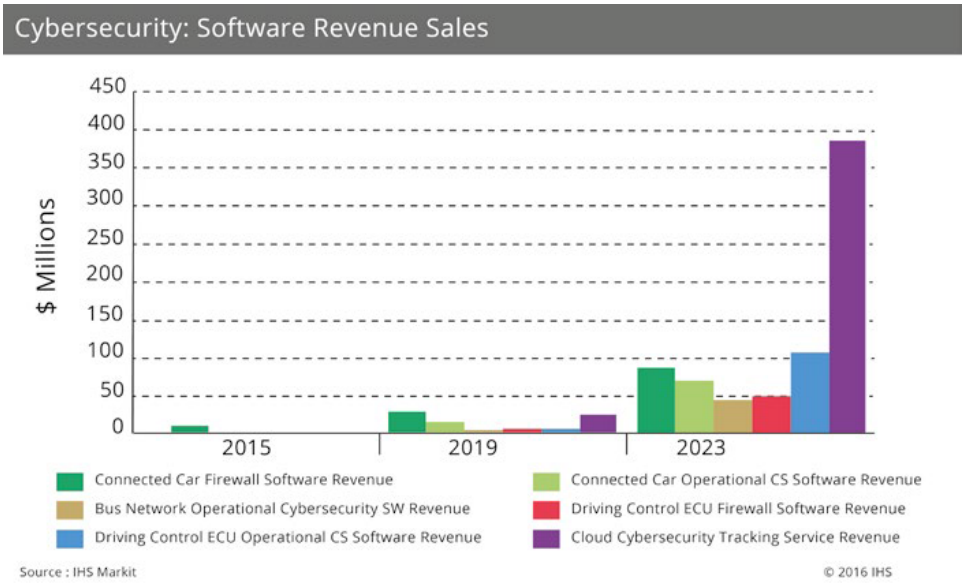


Figure 31 - Cybersecurity Software Revenue Sales

13.2.2. Societal Benefits

Dependability and Trustability are fundamental components of any innovation in the digital economy. It is out of question that novel products and services like personal healthcare monitoring, connected cars or smart homes bring strong benefits for the society, provided that dependability and trustability are taken care of. If this cannot be ensured, there is a significant risk that these innovations will not be accepted by society due to missing consumer confidence.

a.) Benefits for individuals

Individuals tend to get more and more sceptical towards novel digital innovations due unprecedented worldwide cybersecurity attacks like the attack by the Wannacry ransomware cryptoworm in May 2017 that encrypted 400.000 computers globally and demanded ransom payments in the Bitcoin cryptocurrency, or Safety issues such as the Toyota throttle bug causing the death of one occupant, and having cost more than $1 Billion. In addition, trust of individuals is also massively impacted by privacy concerns, because people don't have any feeling anymore who accesses their private data. According to KPMG survey in 2016 [3], 55% of consumers surveyed globally said they had decided against buying something online due to privacy concerns. Figure 32 also shows these increasing concerns for online activities. Safety aspects have a major impact in case of public knowledge of accidents due to technical failure. Moreover safety challenges are getting quite tough because of complex functionalities (autonomous car, avionics for dense traffic) and because of security vulnerabilities of interconnected systems.

Hence, if European industry manages to create dependable, trustworthy and transparent products and services, a strong benefit for individuals will be seen to regain control over this loss of trust.

DRAFT

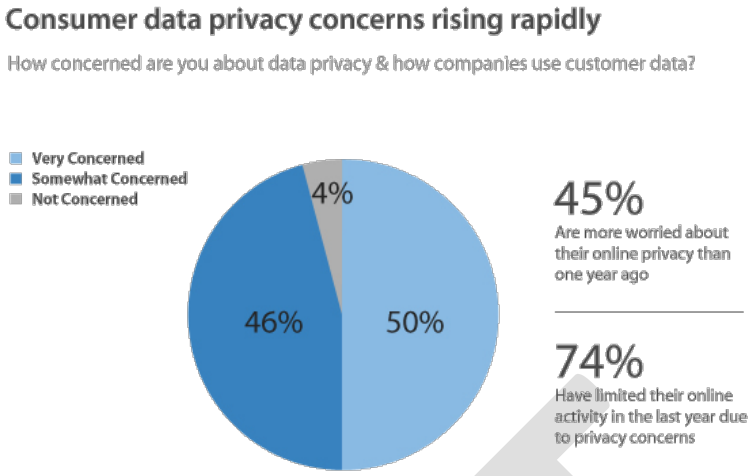


Figure 32 - Consumer data privacy concerns for online activities [4]

b.) Benefits for organisations and businesses

Businesses will benefit from proactively tackling security and privacy issues in one of several ways: protecting the brand name, offering a competitive advantage from integrating privacy and security features into products and services, and creating new products and services designed to protect personal data. The most important characteristics for businesses in the future will be the aspect that they are perceived as trusted companies. Only as trusted organisations, they can maintain a long-term relationship to their customers. New "trusted products" represent a great opportunity for European companies, for example with the development of a "Trusted IoT" label 0. Companies do also benefit from safety assessment and certification.

13.3. Introduction to Major Challenges

13.3.1. Major Challenge 1: Ensuring safety, security and privacy by design

Breaches of sensitive data, mass disinformation campaigns, cyberespionage and attacks on critical infrastructure – these are no longer futuristic threats, but real events that affect individuals, businesses and governments on a daily basis. Yet they remain largely unprosecuted. Increasingly non-conventional threats, using the digital space with complex cyber-attacks, seek to undermine core European values and cohesion. Recent coordinated cyber-attacks across the globe, for which attribution has proved challenging, have demonstrated the vulnerabilities of our societies and institutions.

In this rapidly evolving context, the European Union and its Member States need to anticipate and plan for hitherto unimaginable scenarios in which they would be put under severe attack. Given the non-territorial nature of cyber threats and their increasingly disruptive effect, it is urgent to build up cyber capabilities at all levels – from basic cyber hygiene to advanced cyber intelligence, cyber defence and cyber resilience – in each Member State, and scale up European cooperation.

DRAFT

13.3.1.1. VISION

Although the shift towards a digital world offers huge opportunities, it also comes with new types of risks and threats. As all sectors of our lives increasingly depend on cyber activity, any one of them could be targeted by a cyberattack.

These attacks can be carried out at the micro level, targeting individual citizens and businesses, or – as is increasingly the case – at the macro level, with a view to destabilising governmental institutions and state security, public policies and entire economies 0.

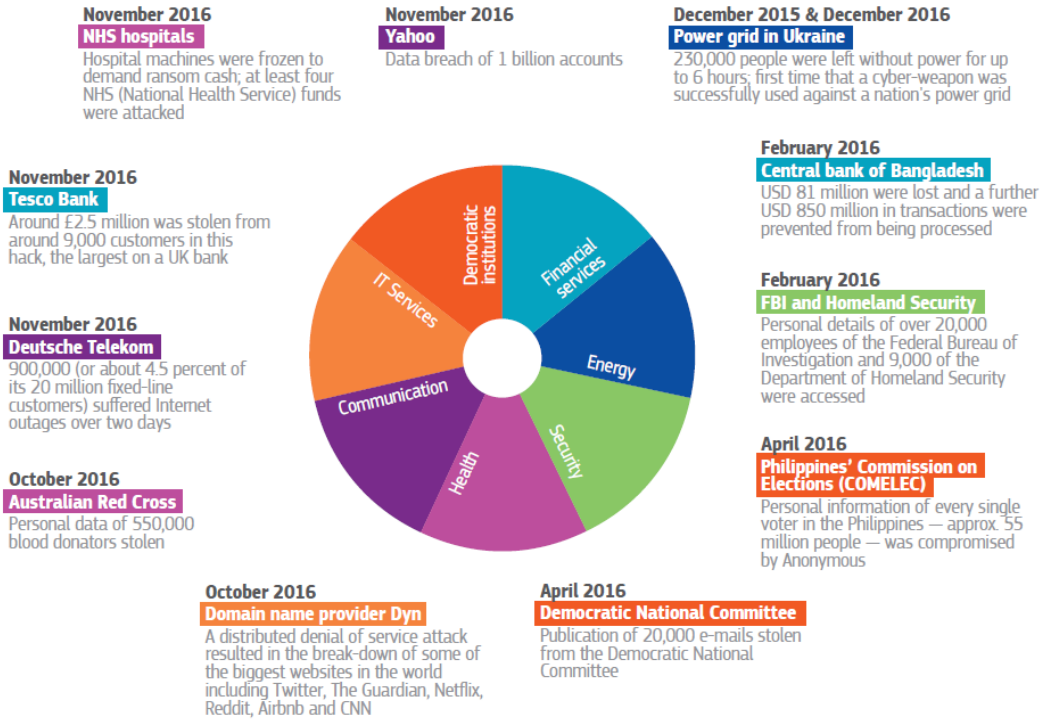


Figure 33 - - No critical sector escapes the cyber threat. This figure features only a small selection of incidents that took place in 2016. Many more attacks occur every day all over the world.

Apart from the indirect transversal destabilising impact, the sheer economic value of these breaches is huge. Restricting the outlook just in the European Union, the average cost of a breach in 2017 fluctuates from $2.8m to $4.6m, being then a large loss factor for the targeted organisation [7].

The landscape described till now – in which we move, live, create trust and produce sensitive data, and in which our systems, hardware and software have to reside for way longer than 1.5 years, whereas for some sector like railway, or automotive, ten times that – is much more wild and balkanised than we would like to think. This is the very reason why security, safety and privacy cannot be plugged in any system or software "at a later stage". Instead, they have to be rooted in the foundations, supporting and being integrated in hardware and software definition, design, development and deployment, and during operation and optimisation.

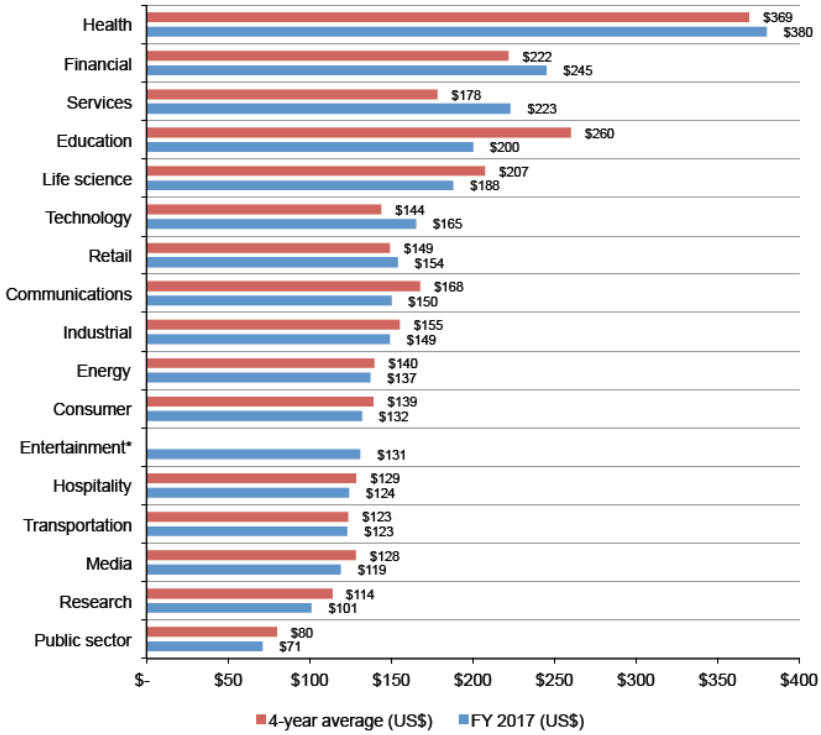


Figure 34 - Per capita cost by industry classification. *Historical data are not available for all years. Measured in US$

13.3.1.2. SCOPE AND AMBITION

The scope of this Major Challenge covers dependability and trustability from design to deployment, with a further glance to the hardware and software life cycle. It covers the enablers to be as future-proof as industrially imaginable today, so to be reliable and resistant to attack techniques envisionable 5-7 years from now. It covers centralised, cloud-based and edge paradigm as well as both industrial and consumer worlds, striving to cover the short-life and extremely manifold consumer scenario and the long-life, reliability-centric industrial one.

The ambition is to facilitate the worldwide uptake of "European Technology" and infrastructure with the goal to earn international reputation for secure, safe, dependable and trustable hardware, software and hybrid definition, design, development and deployment.

13.3.1.3. HIGH PRIORITY R&D&I AREAS

Activity field 1: **Reinforce the Design**

- Strengthened methods for risk management, specifications, architecture and development, development, integration, verification and validation
- New methods and tools for formal verification of specifications, designs and implementations (model level proofs, source code analysis, binary analysis, hardware analysis, etc…)
- New design tools Safety/security engineering

- Delivering high-assurance proofs over the whole life cycle
- Design to fail securely – Cyber threat analysis, susceptibility, assessment, drive pattern of failure
- Multi-level security assessment tools (may they be for security certifications or the security characterizations)
- Certification and standardisation of the complete life cycle of hardware and software (by components and by relations with other components)
- Combined safety and security certification
- Support the evaluation of the systems examined within the safety/security assessment process
- Hardware/Software and hybrid track record
- Security and safety for hardware and software throughout the whole lifecycle
- Real-time safe high-performance computing
- Modeling of safety and security requirements in early design steps to get certification approval and enable incremental certification
- Design methods and tools for Safety and Security Co-Engineering (Modelling, Dependencies, Analysis)
- Architectural principles to support dynamic safety evaluation and assurance (runtime certification/validation)
- Architecture principles supporting compositional safety and security proofs

Activity field 2: **Harden the Edge**

- On-Chip Encryption
- Integrated security, privacy, trust and data protection solutions or smart systems
- Addition of security capabilities to non-secure legacy technologies,
- Integration of hardware and software
- Safe & Secure execution platform
- Safe and Secure certifiable software infrastructures
- Power efficient security features
- Secured devices – Trusted boot, trusted execution, authentication, anti-counterfeiting mechanisms
- Resistance to eavesdropping & injection attacks
- Cyber-security to make products tamper-proof in attacks from hackers
- Tamper Proof technologies
- Segregation and isolation of functional layers of components communication architecture
- Secure real-time systems, protocols, packaging, chip architecture
- Mitigate processor performance variability
- Secure sensor data storage in a standardized way
- (Secure) HW Upgrades and SW Updates
- Multi-tenancy in embedded hardware infrastructures
- Virtualisation and hypervisoring

Activity field 3: **Protect the Reach**

DRAFT

- Standards, information models and interoperability for smart systems integration
- Secured device management
- Certification of safe and secure products (certification standards, design rules, testing and inspection methods, certification scheme for third party evaluation)
- Modular certification
- Certificate management and distribution including certificate revocation lists
- Secured availability and maintainability within product lifecycle
- Quantum Computing exploitation and/or attack hardness
- Risk Management

13.3.1.4. COMPETITIVE SITUATION

Speaking of information technology, there is little excellence that is entirely born and raised in the EU, as base industrial technologies are dominated by giants like Intel, CISCO, Microsoft and the US in general. At the same time, European framework programmes are fostering basic STEM research and capabilities we need to look upon for our challenge, like the Quantum Flagship 0.

In the domain of engineering theory, methods, languages and tools, the European ecosystem has been a significant contributor over the past decades, both in the formal and the semi-formal design areas. Further developing these methods for effective applicability to complex systems in industry remains a challenge, where supporting a good combination of European academics, tool vendors and industry will be instrumental.

From an industrial point of view, the European ecosystem possesses a huge potential in the research and design through the leadership in embedded systems and semiconductors. When utilising this advantage, European industry has a strong chance to increase market shares for safe, secure, and privacy-preserving systems.

13.3.1.5. EXPECTED ACHIEVEMENTS

Expected achievements are secure, safe, dependable and trustable design methodologies, practices, and standards for products and infrastructure that customers can rely on.

13.3.2. Major Challenge 2: Ensuring Reliability and Functional Safety

13.3.2.1. VISION

The vision of the Major Challenge 2 is to provide all means and methods needed for the new ECS solutions to meet the reliability and functional safety targets. This shall even be achieved under the following conditions, which actually rather increase the risks of early and wear-out failures or software defects and worsen the severity of their consequences:

- Continuous growth in number, complexity, and diversity of the functional features, of the devices and components integrated as well as of the technologies and the materials involved in each product

- Increase in reliability and safety level to be achieved by the products, which will simultaneously and more frequently be deployed to ever harsher environments
- Decrease in time-to-market and cost per product due to the stronger global competition
- Higher complexity and depth of the supply chain raises the risk of hidden quality issues

13.3.2.2. SCOPE AND AMBITION

When creating new functionalities and/or increasing the performance of ECS, the concerns of reliability and functional safety shall be accounted for right from the start of the development. This avoids wrong choices, which otherwise, may lead to costly and time-consuming repetitions of several development steps or even major parts of the development. In worst case, unreliable products could enter the market with dramatic consequences for customers and supplier. The improvements in reliability and safety methodology methodologies as well as and their prompt implementation in transfer into industrial practice by R&D&I actions strictly aim at enabling the new European ECS products to enter the world market fast, and to gain market shares rapidly, and to keep leadership positions sustainably in order to secure jobs and wealth in Europe:

- Determination of the 'Physics of Failure' (**PoF**) for all key failure modes and interactions
- Development of fast and comprehensive technology / product **qualification** schemes
- Creation of commonly accepted PoF based design for reliability, testing, manufacturing, … (**DfX**) methods based on calibrated models and validated numerical simulations and/or formal approaches
- Strategies for field data collection, prognostic health management (**PHM**) and autonomic development of ECS

13.3.2.3. HIGH PRIORITY R&D&I AREAS

Activity field 1: **Experimental techniques for PoF assessment, analytics, and testing**

- Physical failure analysis techniques
- Realistic material and interface characterisation depending on actual dimensions, fabrication process conditions, ageing effects etc. covering all critical structures
- Tamper-resistant design, manufacturing & packaging of integrated circuits
- Comprehensive understanding of failure mechanisms, lifetime prediction models
- Integrated mission profile sensors in field products avoiding security or privacy threats
- Wafer fab in-line and off-line tests for electronics, sensors, and actuators, and complex hardware (e.g., multicore, GPU) also covering interaction effects such as, heterogeneous 3D integration, packaging approaches for advanced nodes technologies
- Accelerated testing methods (e.g., high temperature, high power application) based on mission profiles and failure data (from field use and from tests)
- Multi-mode loading based on mission profile

Activity field 2: **Pro-active DfX strategies based on virtual techniques**

- Virtual testing – design of very harsh tests for component (and system) characterisation

DRAFT

- Mathematical reliability models also accounting for the interdependencies between the hierarchy levels: device – component – system
- Mathematical modelling of competing and/or super-imposed failure modes
- Failure prevention and avoidance strategies based on a hierarchical reliability approaches
- Virtual prototyping – DfX – building blocks
- Standardisation of the simulation driven DfX
- Automation of reliability assessment based on electronic design input
- Coordination action: Providing room for companies and research institutes to exchange expertise on reliability issues for advanced technologies
- European portal for DfR service provided by institutes and SMEs (provides access to DfR service at reduced cost - similar to 'Europractice' for wafer processing service)

Activity field 3: **Functional safety – Prognostic Health Management (PHM)**

- Self-diagnostic tools and robust control algorithms, validated by physical fault-injection techniques (e.g., by using end-of-life components)
- Hierarchical and scalable health management architectures, integrating diagnostic and prognostic capabilities from components to complete systems
- Monitoring test structures and/or monitor procedures on component and module level for monitoring temperatures, operating modes, parameter drifts, interconnect degradation etc.
- Identification of early warning failure indicators and development of methods for predicting the remaining useful life of the concrete system in its use conditions
- Functional safety aspects for autonomous systems including self-diagnostic and self-repair capabilities
- Development of schemes and tools using machine learning technique and AI for PHM
- Big sensor data management (data fusion, find correlations, secure communication)
- Safety certification on key domains like automotive, railway, industrial machinery, and avionics

Activity field 4: **Dynamic adaptation and configuration, self-repair capabilities, resilience of complex systems**

- Self-diagnostic architecture principles 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.
- Architectures, which support distribution, modularity, and fault containment units in order to isolate faults.
- Support for dependable dynamic configuration and adaptation/maintenance: as to cope with components to appear and to disappear, as ECS devices to connect/disconnect, and communication links are to be established / released depending on the actual availability of network connectivity; this includes e.g. patching, to adapt to security countermeasures.

DRAFT

- Concepts for run-time or dynamic certification/qualification, like run-time or dynamic safety contracts, to ensure continuing trust in dynamic adaptive systems in changing environments.
- Concepts for SoS integration including the issue of legacy system integration.
- Concepts and architecture principles for trustable integration and verification & validation of intelligent functions in systems / products: dedicated uncertainty management models and mechanisms (monitoring and issue detection) for automated or human-in-the loop online risk management. This includes machine-interpretation of situations (situational awareness) and machine-learning, for handling SotiF (Safety of the intended Functionality) and fail-operational issues, decision taking, prediction and planning.

13.3.2.4. COMPETITIVE SITUATION

The current reliability and safety assessment practice shows the following shortcomings:

- PoF & Qualification: Predefined qualification plans are applied based on inherited standards often without adaption to the specific new PoF situation.
- DfX: While virtual schemes based on numerical simulation are widely used for functional design, they lack a systematic approach when used for reliability assessments.
- Lifetime prediction: System-level lifetime predictions are still based on MIL standards (FIDES, Telcordia etc.) with a constant failure rate statistics.
- PHM: Rarely any solutions on component or system level are available except for high-end products (e.g., in avionics and energy infrastructure). Search for early warning failure indicators is still at basic research stage.
- Dynamic adaptation: Highly dynamic architectures are pushed by data center providers to provide resilience and adaptability such as RackScale architecture, but there are not designed with safety in mind.

Intense research in the U.S and Asia tackles these shortcomings. Local conferences disseminate the results. Europe contributes details but does not set the standards.

13.3.2.5. EXPECTED ACHIEVEMENTS

Public authorities and customers will accept innovative products only with all reliability and safety requirements fully met besides all the new functional features offered. Hence, this transversal topic is most essential for paving the way to the market for the new ECS products. Moreover, reliability and safety are concerns with great influence on customer satisfaction and trust. They enable generating a positive attitude of easy acceptance that helps unleashing the great potential of ECS technologies for creating products that benefit the public health, help the ecology, and create economic growth at the same time.

DRAFT

13.3.3. Major Challenge 3: Ensuring secure, safe and trustable connectivity and infrastructure

13.3.3.1. VISION

More and more Internet-connected devices find their way into homes and businesses. According to Gartner 0, there will be 20 billion Internet-connected devices by 2020. However, insecure IoT devices pose an increasing risk to both consumers and the basic functionality of the Internet. Insecure devices serve as building blocks for botnets, which in turn provide attackers access to compromised devices, perform DDoS attacks, send spam as well as steal personal and sensitive data.

Figure 35 - Sustained attack campaigns are constantly hitting companies

The sheer number and volume of attacks rendered possible by the IoT explosion makes very clear the paramount importance of having a sound secure and trustable infrastructure. Globally, we assisted to the three largest attacks in history, aimed at assessing the capabilities to literally bring down the internet. Security personnel are concerned the use of DDoS attacks could cause wide scale interruptions to our critical infrastructure, including public health and safety services. These high number of sources are most probably driven by attacks from Mirai botnets. Mirai is a malware that turns networked devices into remotely controlled "bots" that can be used as part of a botnet in large-scale network attacks. It primarily targets online consumer devices such as IP cameras and home routers [1].

Without a significant change in how the IoT industry approaches security, the explosion of IoT devices increases the risk to consumers and the whole industry. Therefore, industry must work to develop and adopt the necessary standards to ensure connected devices with sufficient incorporated security. This required change is addressed by the vision of secure and trustable connected devices that are robust, use broadly adopted security standards and have strong certification testing and enforcement mechanisms. Involved infrastructure like networks and cloud computing systems must be capable of detecting and containing potential security incidents.

13.3.3.2. SCOPE AND AMBITION

The scope of this Major Challenge covers security and trustability for devices with communication capabilities, either via Internet connectivity or locally towards other nodes. Safety is also covered in case safety functions are realised via connected devices.

This includes IoT nodes like networked sensors and actuators, fixed and wireless networks as well as centralized (cloud computing systems) and non-centralized (fog and edge computing) processing elements. It also covers security for communication protocols on different layers.

The ambition is to facilitate the worldwide uptake of "European Technology" and infrastructure with the goal to earn international reputation for secure, safe and trustable networking elements, in particular for industrial applications.

13.3.3.3. HIGH PRIORITY R&D&I AREAS

Activity field 1: **Secure IoT devices**

- Processes for adding new devices/capabilities to the network ("onboarding")
- Strong security with immutable, attestable and unique device identifiers
- Onboarding "weak" AI at the edge
- Authentication, Authorization, Revokability and Accountability
- Hardened devices with high integrity, confidentiality and availability
- Inherently trusted processor that would, by design, ensure security properties
- Lifecycle management
- Standardized, safe and secure "over the air" SW updates
- End-of-life (EOL) / End-of-Support (EOS) functionality
- Upgradable security for devices with long service life
- Secure components and secured ownership within an insecure environment
- Certification processes, testing and enforcement

Activity field 2: **Secure communication protocols**

- Ensuring high standards for secured communication
- Secure interoperability of protocols, components and communications
- Monitoring, detection and mitigation of security issues on communication protocols
- Quantum key distribution (aka "Quantum Cryptography")
- Formal verification of protocols and mechanisms
- Production of verified reference implementations of standard protocols and the guidelines to securely deploy them

Activity field 3: **Secure IT infrastructure**

- Infrastructure resilience and adaptability to new threats
- Continuous' secure end-to-end systems
- Secure cloud solutions
- Secure edge/fog computing
- Secure wireless and wired networks
- Low-power wide area networks
- 5G-related aspects of softwarisation, SDN and security of professional communications
- Artificial Intelligence for networks and components autonomy, network behaviour and self-adaptivity

DRAFT

13.3.3.4. COMPETITIVE SITUATION

When looking at IoT technology, the worldwide market is dominated by US companies like Apple, Amazon, Microsoft or Google. These companies act worldwide and provide cloud computing platforms and data centers in many countries close to their customers. Wireless technology on the other hand is traditionally strong in Europe, originating from the success of the GSM technology up to ongoing development for 5G systems. Europe has several renowned, internationally acting mobile network equipment suppliers. However, recently competition from Chinese companies in this field has significantly increased.

From an industrial point of view, European companies possess a huge potential in the IoT market through the leadership in embedded systems and semiconductors, particularly in automotive industry. When utilising this advantage, European industry has a strong chance to increase market shares for secure connectivity and infrastructure.

13.3.3.5. EXPECTED ACHIEVEMENTS

Expected achievements are secure, safe and trustable connected products and infrastructure that customers can rely on. This will be achieved with certified products according to a comprehensive security standard consisting of elements from the described high priority R&D&I areas above.

13.3.4. Major Challenge 4: Managing privacy, data protection and human interaction

13.3.4.1. VISION

More and more Internet-connected devices find their way into homes and businesses. According to Gartner there will be 20 billion Internet-connected devices by 2020. As of today, the IoT already generates a vast amount of information about our activities. This data can be used to create unexpected and undesirable influence to people. For example, some rental car companies include sensors in vehicles to warn drivers if they drive too recklessly. If such kind of data is given to car insurance companies, insurances may deny users without transparently providing reasons to users. There are many similar examples that make people nervous about the use of big data technology.

Several measures have already been taken by the European Parliament and its national counterparts which aim to strengthen Europe's resilience. Two of these are the EU General Data Protection Regulation (GDPR) (Regulation (EU) 2016/679) 0) and the EU Directive on security of network and information systems (EU Directive 2016/1148) 0) as well as corresponding national laws in many EU Member States. The EU Directive 2016/1148 (better known as NIS directive) states that every operator of critical infrastructure and digital service providers must cooperate by exchanging security relevant information and are liable to maintain a certain level of security.

The acceptability of novel innovations with regard to privacy also involves strong human interaction including non-technical factors like psychological, social and work contextual

factors. Therefore people must be able to transparently see, how much and to what extend data about themselves is being shared in products and services, e.g. with the vision of using a "Trusted IoT label" *as identified by the European Commission 0.*

13.3.4.2. SCOPE AND AMBITION

The scope of this Major Challenge is to develop methods and framework enabling the deployment of privacy, data protection and human interaction for different market without impacting customer acceptance. Hence, different contrary requirements shall be satisfied:

- Limited computing resources vs. appropriate security level and real-time requirements
- Consistent (interoperable) Integration in different application domains having heterogeneous technical and market constraints
- Agility for new product development and optimized time to market while integrating and validating appropriate privacy framework
- High degree of product customization and validation of privacy attributes
- Fulfilment of European directives and national regulations
- Data management and ownership in multi-stakeholder (multi-sided) market

13.3.4.3. HIGH PRIORITY R&D&I AREAS

Activity field 1: **(Local) Technical solutions for privacy and data management**

- Security for privacy and personal data protection
- Identity, access management and authentication mechanisms
- Trusted devices based on block chain
- Secure aware data processing and storage
- Biometric technologies

Activity field 2: **(Global) Data management for privacy and protection**

- Data privacy & data ownership (use of enormous amount of data respecting privacy concerns)
- Data Protection, data standards
- Data pedigree
- Definition of models for data governance
- Supply chain security and zero-trust supply chain
- IoT Forensic capability for insurance & investigation purposes

Activity field 3: **Human interaction**

- Evaluation and experimentation for ECS platforms directly interfacing human decisions
- Establish a consensus for societal expectations for safety margin, ethic and mobility issues
- User acceptability and usability of secure solutions
- Design of trusted systems considering non-technical factors including psychological, social and work contextual factors

DRAFT

- Evaluation and experimentation using extended simulation and test-bed infrastructures for an integration of Cyber-Physical Systems Platforms that directly interface with human decisions.

13.3.4.4. COMPETITIVE SITUATION

The European General Data Protection Regulation (GDPR) has a global impact after it goes into effect on May 25, 2018, because it not only affects EU companies, but also any companies that do business with the EU. Hence, this stringent data privacy regulation already creates a leading role for Europe since other countries implement and follow it even for their own markets.

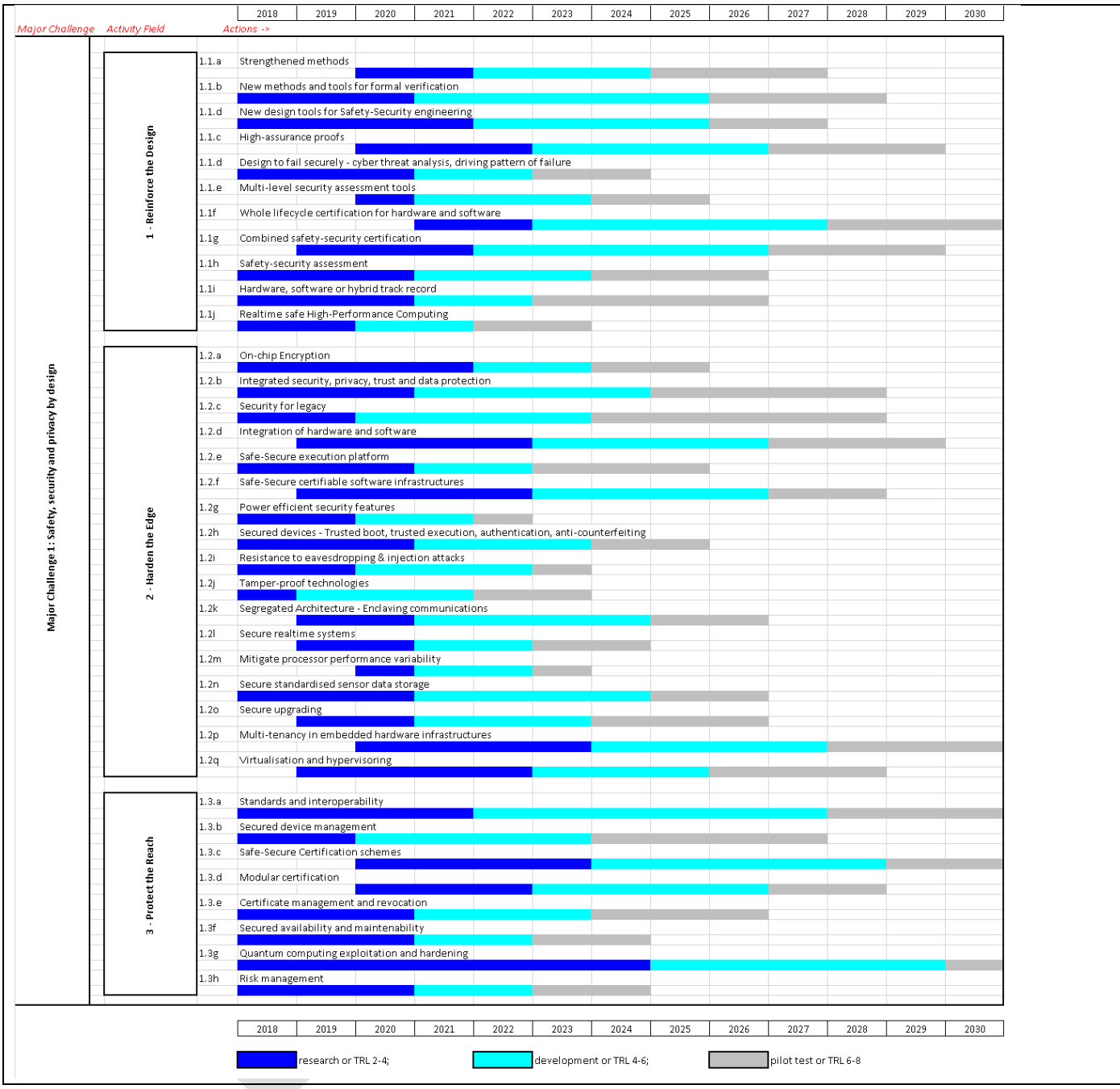
From an application point of view, European companies have a leading edge in different markets such as automotive and semiconductors or advanced production. Exactly the mix between domain-specific knowledge (subject matters) and connectivity technology will be required to create the added value at the end customer market.

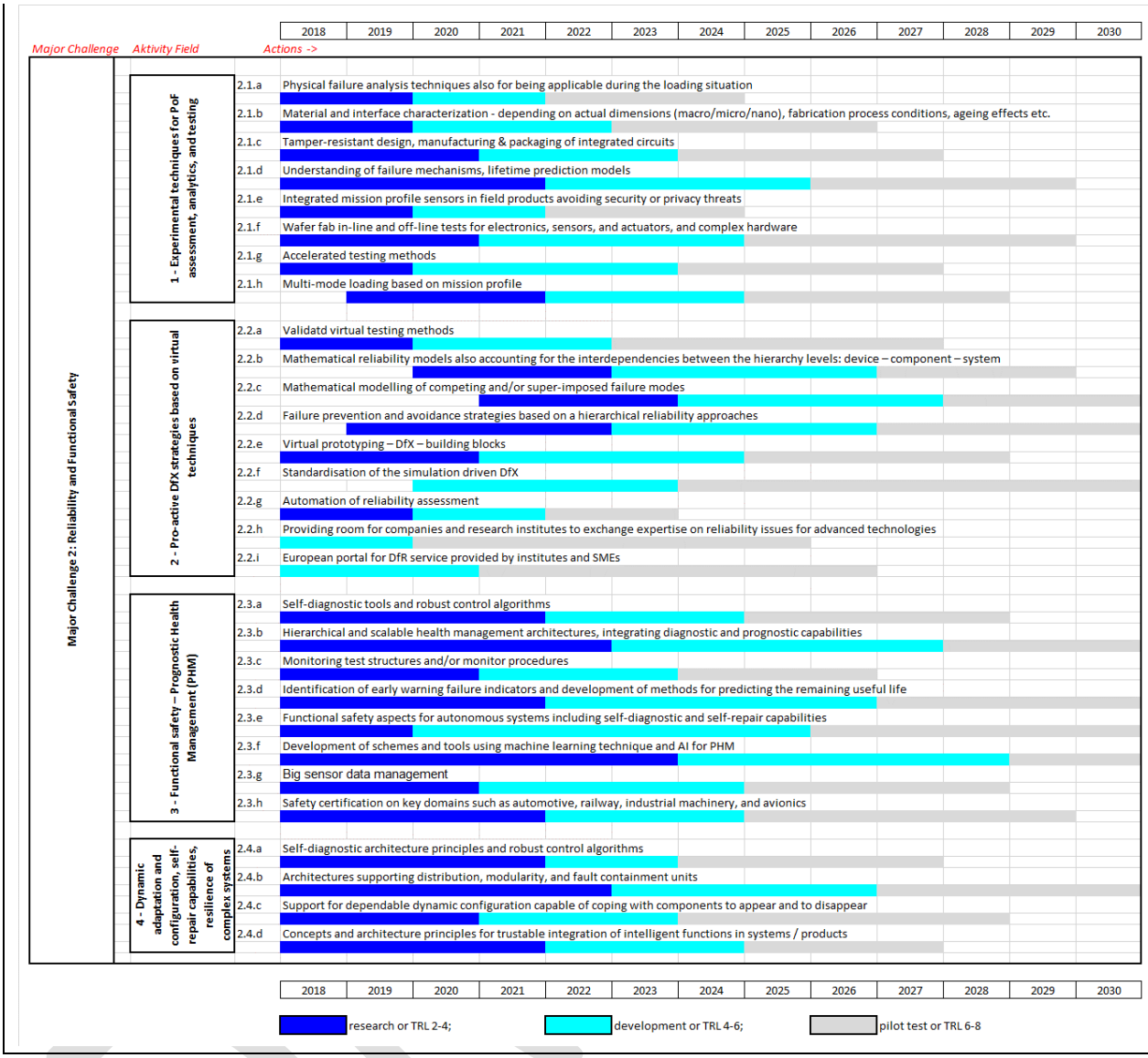
13.3.4.5. EXPECTED ACHIEVEMENTS

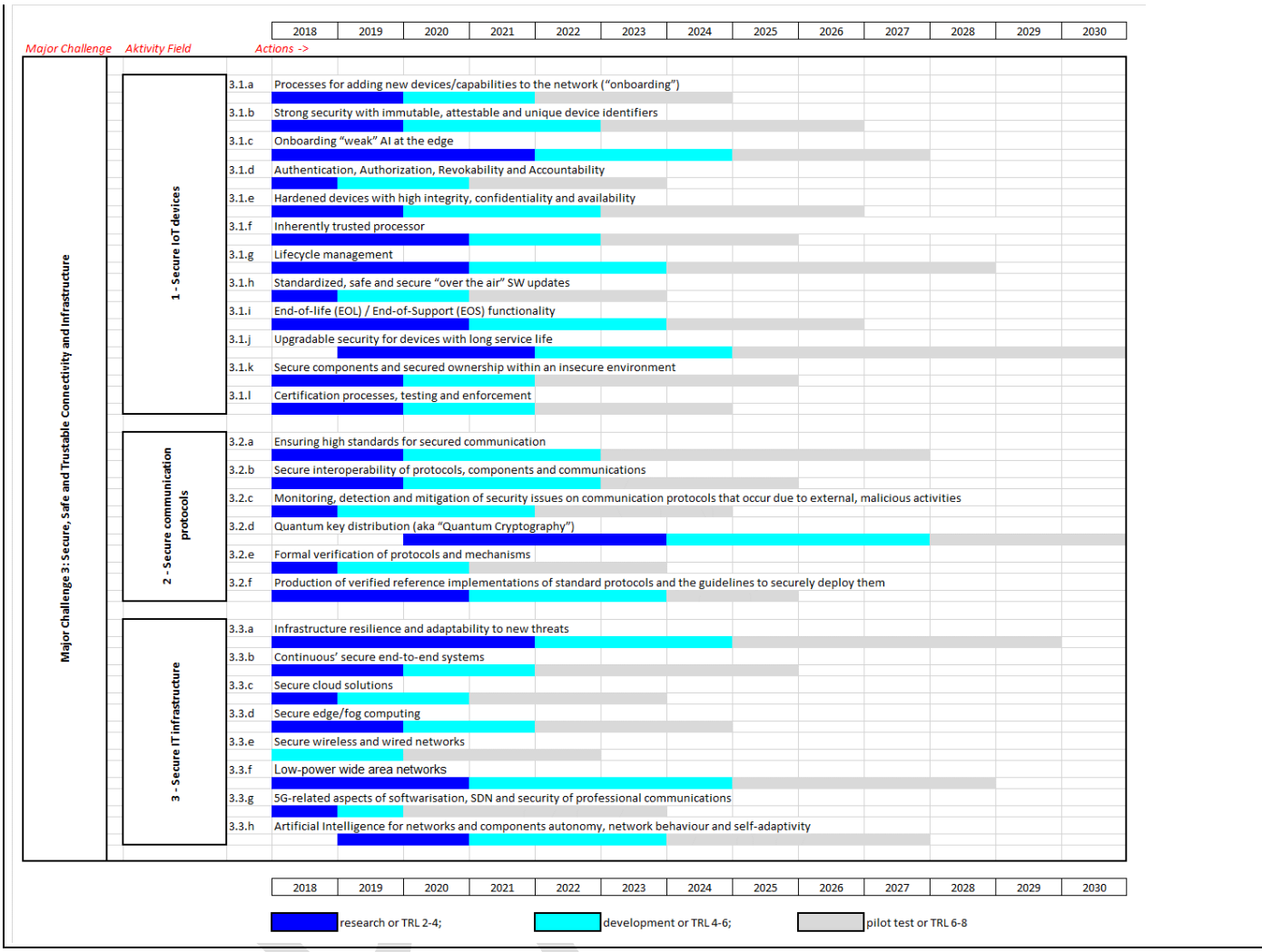
The expected achievements are a set of frameworks to facilitate the uptake of connected services and products for all industry sectors, while ensuring fulfilment of European directives and national regulation. The development of these methods is inevitable for the success and security of our future smart environments, for the customer trust and acceptance and, therefore, is necessary to maintain the European society and its position in a global competition on economic markets.

DRAFT

13.4. Timeframes




Major Challenge
Aktivity Field
Actions ->
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Major Challenge 2: Reliability and Functional Safety
1 - Experimental techniques for PoF assessment, analytics, and testing
2.1.a Physical failure analysis techniques also for being applicable during the loading situation
2.1.b Material and interface characterization - depending on actual dimensions (macro/micro/nano), fabrication process conditions, ageing effects etc.
2.1.c Tamper-resistant design, manufacturing & packaging of integrated circuits
2.1.d Understanding of failure mechanisms, lifetime prediction models
2.1.e Integrated mission profile sensors in field products avoiding security or privacy threats
2.1.f Wafer fab in-line and off-line tests for electronics, sensors, and actuators, and complex hardware
2.1.g Accelerated testing methods
2.1.h Multi-mode loading based on mission profile
2 - Pro-active DfX strategies based on virtual techniques
2.2.a Validatd virtual testing methods
2.2.b Mathematical reliability models also accounting for the interdependencies between the hierarchy levels: device – component – system
2.2.c Mathematical modelling of competing and/or super-imposed failure modes
2.2.d Failure prevention and avoidance strategies based on a hierarchical reliability approaches
2.2.e Virtual prototyping – DfX – building blocks
2.2.f Standardisation of the simulation driven DfX
2.2.g Automation of reliability assessment
2.2.h Providing room for companies and research institutes to exchange expertise on reliability issues for advanced technologies
2.2.i European portal for DfR service provided by institutes and SMEs
3 - Functional safety – Prognostic Health Management (PHM)
2.3.a Self-diagnostic tools and robust control algorithms
2.3.b Hierarchical and scalable health management architectures, integrating diagnostic and prognostic capabilities
2.3.c Monitoring test structures and/or monitor procedures
2.3.d Identification of early warning failure indicators and development of methods for predicting the remaining useful life
2.3.e Functional safety aspects for autonomous systems including self-diagnostic and self-repair capabilities
2.3.f Development of schemes and tools using machine learning technique and AI for PHM
2.3.g Big sensor data management
2.3.h Safety certification on key domains such as automotive, railway, industrial machinery, and avionics
4 - Dynamic adaptation and configuration, self-repair capabilities, resilience of complex systems
2.4.a Self-diagnostic architecture principles and robust control algorithms
2.4.b Architectures supporting distribution, modularity, and fault containment units
2.4.c Support for dependable dynamic configuration capable of coping with components to appear and to disappear
2.4.d Concepts and architecture principles for trustable integration of intelligent functions in systems / products
research or TRL 2-4;
development or TRL 4-6;
pilot test or TRL 6-8


Major Challenge
Aktivity Field
Actions ->
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Major Challenge 3: Secure, Safe and Trustable Connectivity and Infrastructure
1 - Secure IoT devices
3.1.a Processes for adding new devices/capabilities to the network ("onboarding")
3.1.b Strong security with immutable, attestable and unique device identifiers
3.1.c Onboarding "weak" AI at the edge
3.1.d Authentication, Authorization, Revokability and Accountability
3.1.e Hardened devices with high integrity, confidentiality and availability
3.1.f Inherently trusted processor
3.1.g Lifecycle management
3.1.h Standardized, safe and secure "over the air" SW updates
3.1.i End-of-life (EOL) / End-of-Support (EOS) functionality
3.1.j Upgradable security for devices with long service life
3.1.k Secure components and secured ownership within an insecure environment
3.1.l Certification processes, testing and enforcement
2 - Secure communication protocols
3.2.a Ensuring high standards for secured communication
3.2.b Secure interoperability of protocols, components and communications
3.2.c Monitoring, detection and mitigation of security issues on communication protocols that occur due to external, malicious activities
3.2.d Quantum key distribution (aka "Quantum Cryptography")
3.2.e Formal verification of protocols and mechanisms
3.2.f Production of verified reference implementations of standard protocols and the guidelines to securely deploy them
3 - Secure IT infrastructure
3.3.a Infrastructure resilience and adaptability to new threats
3.3.b Continuous' secure end-to-end systems
3.3.c Secure cloud solutions
3.3.d Secure edge/fog computing
3.3.e Secure wireless and wired networks
3.3.f Low-power wide area networks
3.3.g 5G-related aspects of softwarisation, SDN and security of professional communications
3.3.h Artificial Intelligence for networks and components autonomy, network behaviour and self-adaptivity
research or TRL 2-4;
development or TRL 4-6;
pilot test or TRL 6-8

DRAFT

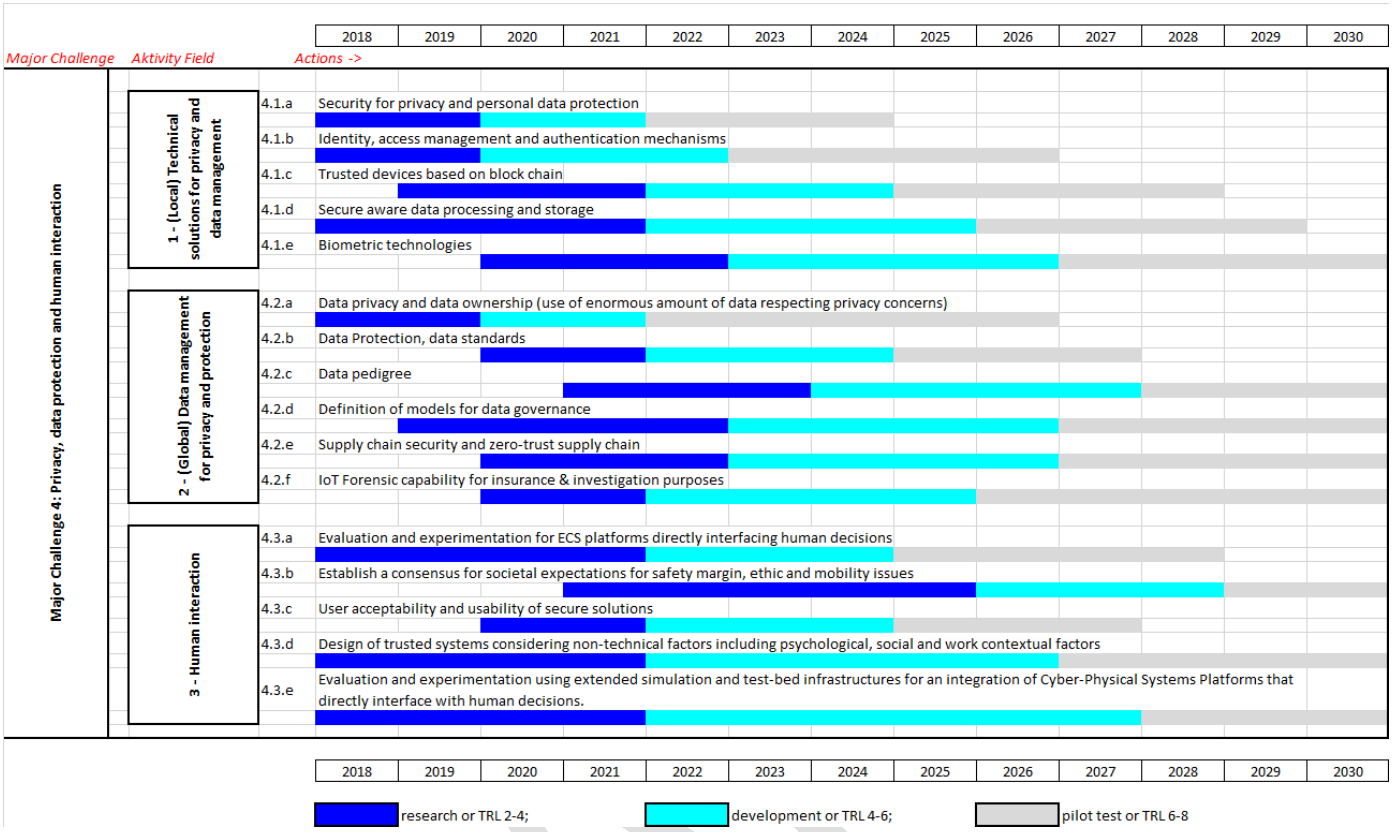


Figure 36 - Safety, Security and Reliability timelines

DRAFT

13.5. Synergies with other themes

	MC1: Safety, security and privacy by design			MC2: Reliability and Functional Safety				MC3: Secure, safe and trustable connectivity and infrastructure			MC4: Privacy, data protection and human interaction		
	Secure the Design	Harden the Edge	Protect the Reach	PoF assessment & analytics, PoF-based testing	Pro-active DfX based on virtual techniques	Functional safety by PHM	Dynamic adaptation and configuration, self-repair capabilities, resilience of complex systems	Secure IoT devices	Secure communication protocols	Secure IT infrastructure	Technical solutions for privacy and data management	Data management for privacy and protection	Human interaction
Transport	x	x	x	X	x	x	x	x	x	x	x	x	x
Health	x	x	x	X	x	x	x	x	x	x	x	x	x
Energy	x	x	x	X	x	X	x	x	x	x	x	x	
Industry	x	x	x	X	x	x	x	x	x	x	x	x	x
Life	x	x	x	X	x		x	x	x	x	x	x	x
Architecture, **D**esign, and **S**ystems **I**ntegration **T**echnology.	x	x	x	X	x	x	x	x	x		x		
Connectivity	x	x	x	X			x	x	x	x	x	x	x
Computing & Storage	x	x	x	X	x	x	x	x	x	x	x	x	
Process Technology, Equip, Mat & ECS Manuf	x	x	x	X	x	x		x	x		x	x	

Figure 37 – Synergies with other chapters

DRAFT

14. Computing and Storage

14.1. Executive Summary

Computing and storage are the fuel of the digital revolution in providing ever increasing performance for existing and new applications at a constant or decreasing cost.

As the Moore's Law started to break down with the size of transistor shrunk down to near the atomic scale, chipmakers face increasingly issues trying to pack more and more transistors onto chip and hence computing turn towards alternative ways to get more computing power including massively parallel, heterogeneous, distributed designs of processors and accelerators. But it has a drastic impact on programming and on the efficient management of the ever-increasing complexity of computing and storage systems. Performance is also shifting from absolute number of operations per second to operations per second and per watt for all domains of computing.

Investigations of new technologies from neuromorphic computing, optical to quantum for the long term open the way to new computing paradigms so new applications drive like Cyber-Physical Systems and Artificial Intelligence.

This trend leads to the following major challenges for computing technologies:

- Increasing performance at acceptable costs
  - For High Performance Computing (HPC)
  - For low power and ultra-low power computing
- Making computing systems more integrated with the real world
- Making "intelligent" machines
- Developing new disruptive technologies: Quantum technologies, neuromorphic computing, optical Computing

14.2. Relevance

14.2.1. Competitive Value

The key ingredient to the digital world is the availability of affordable computing and storage resources. From deeply embedded microcontrollers to supercomputers, our modern civilization demand even more on computing and storage to enable new applications and change our way of life. In less than 10 years, mobile computing, a.k.a smartphone have change the way we see, interact and understand the world. Even in less developed countries, having a smartphone is nearly as vital as food. Computing and storage systems are morphing from classical computers with a screen and a keyboard to smart phones and to deeply embedded systems in the fabric of things.

Computing and storage should also enable more products (diversification) at affordable prices.

This should cover the complete spectrum, from ultra-low power wearable devices to Exascale systems.

While Europe is recognized for its knowhow in software and especially in embedded systems architecture and software, it should continue to invest in this domain to continue to be at the top, despite of the fierce competition or countries like China, India, etc.

European companies are also in the leading pack for embedded microcontrollers. Automotive, IoT and all embedded systems consume a large number of low cost microcontrollers, integrating a complete system, computing, memory, and various peripherals in a single die. Again, a pro-active innovation is necessary to cope with the new applications and constraints, like for Cyber-Physical Systems and Edge computing, especially when local AI is required.

Europe is not present anymore in the "classical" computing such as processors for laptops and desktop, servers and HPC, but the new initiative of the European Commission, "*for the design and development of European low-power processors and related technologies for extreme-scale, high-performance big-data and emerging applications, in the automotive sector for example*" could reactivate an active presence of Europe in that field. The ECS SRA recognize that this initiative is important for Europe.

Coprocessors, GPU and Deep Learning accelerators (and other accelerators) are also more and more important. European solutions exist, but the companies are often bought by foreign companies.

In a world in which some countries are more and more closing onto themselves, not having high end processing capabilities (i.e. relying on buying them for countries out of Europe) might become a weakness. China, Japan, India, Russia are starting to develop their own processing capabilities in order to prevent potential shortage.

14.2.2. Societal benefits

Computing is at the heart of a wide range of fields by powering the utmost systems the human are interacting with. It enables Transformational Science (Climate, Combustion, Biology, Astrophysics, etc…), Scientific Discovery and Data Analytics. The advent of complete or partial autonomous system, in addition to CPS, requires tremendous improvement in the computing fabric. Even if deeply hidden, these computing fabrics have direct or indirect impact on our ways of life: Autonomous systems (car, aircraft, train, etc.), Quality of life (healthcare, transportation, energy, etc.), Communication (Satellite, 5G, etc.).

For example, computing and storage are key for solving societal challenges listed in the previous chapters, like monitoring and using the right amount of material and energy to save goods and energy. They will allow to optimize industrial processes for saving money. It enables cheaper products because they allow to build more efficient solutions. In the

medical domain, for example, it will allow delocalizing healthcare (for example in countryside), where no specialists are available.

New applications, relying on complex computing and storage systems, allows to monitor your heath thanks to smart bracelets or smart watches, and could reduce the impact of heart attack or other health problems. Car will send they local and call for help after an accident. Intelligent applications helping the driver will reduce the number of accident in monitoring the environment and giving warning to the driver. Surveillance systems will allow to improve the security in various locations.

14.3. Major Challenges

14.3.1. Increasing performance at acceptable costs

Efficient systems and management of complexity

14.3.1.1. VISION

This major challenge addresses the course of computing technology and determines whether or not it would allow a 50× increase in peak performance in viable operating costs (i.e. energy, financial cost, reliability, size, etc.) by the 2020-time frame and to continue such progression beyond. Focus will be put on the main technological challenges that might prevent from reaching such an objective: Energy consumption increase, memory and storage limitation, increasing complexity of applications *versus* achievable parallelism and resiliency.

14.3.1.2. SCOPE AND AMBITION

Computing solutions need to cover the whole range of applications, going from low-end IoT devices up to Exascale Computing. The expectation is not just to get more processing power, but at affordable costs: power, size, price, cyber-security. It is a shift from absolute number of operations per second to systems with a high efficiency.

An ambitious goal the High-Performance Computing community has set for itself is *Exascale Computing* as the next major step in computer engineering. The unprecedented level of computing power offered by Exascale is expected to significantly enhance our knowledge for the benefit of a large spectrum of industries including Energy (e.g. modeling and simulation of nuclear engineering analysis, etc.), Bioinformatics and Medical Systems (e.g. multiscale approach to biological modeling, Medical Image Analysis at microscopic/spectral level, pharmaco-genetics, computer-aided surgery, discovery of new therapeutic molecules, etc.), Materials Science (e.g. investigation of 3D molecular structure design of engineering properties), Transportation (as exemplified by aerospace, airframes or autonomous vehicle applications, Entertainment (e.g. virtual reality), and many others.

The autonomous systems (such as automotive, train, aircraft) are requiring embedded vision, complex decision making and sensor processing (Radar, Lidar, Positioning, etc.) that were only possible with HPC systems of few years ago, but need now to be realized with cost and energy effective systems that don't have to be installed in dedicated rooms.

14.3.1.3. COMPETITIVE SITUATION AND GAME CHANGERS.

The major consolidation of the of the semi-conductor market observed in 2015 is continued with new merges still on-going. The top ten players achieved an aggregated market share of almost 60%.

It creates a situation where few major companies are providing computing solutions, notably for the high end, for the world. According to 2017 McLean report, in the top 10 Worlwide Semiconductor Sales leaders, only 2 companies are still European, putting at risk the capability of Europeans to make their own decision. For sovereign domains, but with small volumes, such as HPC, space, aeronautic, military, it may be difficult in 10-15 years to get access to some technologies.

Maintaining a European know-how on these technologies is required to meet the challenges at all stages of the data processing chain. Indeed, the intelligence of today systems is not coming from a single element but from a tight collaboration between distributed elements Smart Sensor, CPS, Iot, Edge, Cloud and HPC. At each level, the large amount of data "*data deluge*", resilience, confidentiality and autonomy requires new innovative computing solutions to satisfy emerging needs, not satisfied anymore but the ""ever shrinking technology nodes" as highlighted in the HiPEAC vision document (http://www.hipeac.net/roadmap). The Industrial and research computing community must support these evolutions by aiming at providing from 1 ExaFlops/s for HPC down to 1 TeraFlops/s/Watt for embedded CPS in 2020.

On the other hand, the Industrial and Automotive industry are seen as growth potential, sectors where European actors are well positioned.

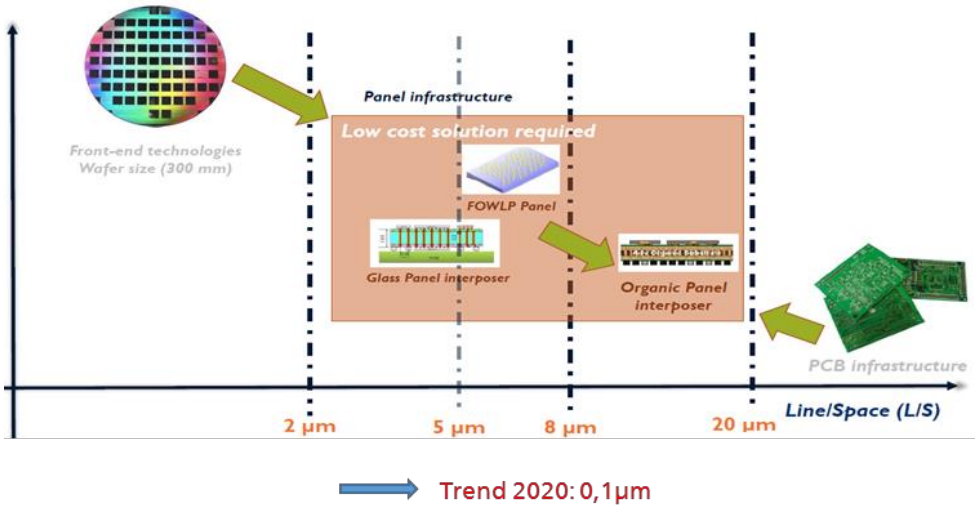


Figure 38 – The heterogeneous integration domain in electronic components merges the conventional PCB with the wafer level technologies (source: Fraunhofer IZM).

In addition to this good positioning, the forecast of the annual growth rates in Europe will be higher than other regions.

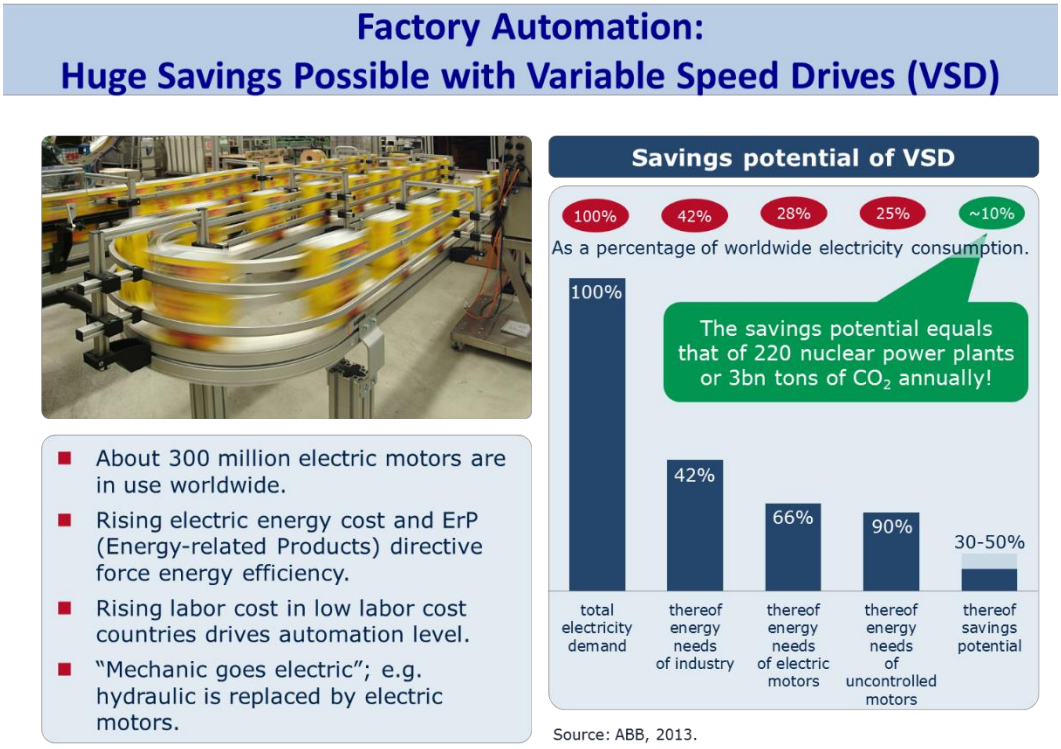


Figure 39 – Energy saving potential of S/C power technologies

The Europe positioning must be maintained on these innovative fields, and leverage on it to gain on others sectors. The industrial applications (such as Industry 4.0) and automotive (such as autonomous car) are launch pads for new technologies trying to cope with the challenges that are shared by embedded, mobile, server and HPC domains: **energy and power dissipation, and complexity management**. The safety requirements, applicable even in loss of connectivity, prevents Cloud-only based solutions for Artificial Intelligence, Image processing, Complex decision making (including preserving human life) with strong real-time constraints

CPS used in harsh environment (high temperature, radiation, vibration, etc.) requires either dedicated or finely tuned architecture to run critical and highly intensive application: on-board satellite data processing, aircraft or cars self-monitoring.

14.3.1.4. HIGH PRIORITY R&D&I AREAS

The hardware and architecture challenges

Next generation hardware[38] requires a huge challenge: an increase factor of at least 50 in performance to be combined with technology breakthroughs to reduce the power

[38] The state-of-the-art is illustrated in the following respective references:

consumption by a factor of 100 (e.g. an extrapolation of the power load using current technology will require over a gigawatt for future exascale systems). The technical axes of exploration for *power reduction* in hardware design include: energy efficient building blocks (CPU, memory, reducing length of interconnects) possibly based on 3D silicon technologies, extensive usage of accelerated computing technologies (e.g. GPU, FPGA) to complement general-purpose processor, domain specific integration (SiP, SoC), domain specific customized accelerators (e.g. for deep-learning, cryptography, …), silicon-photonic backplane, cooling and packaging technologies, etc.

Progress on ultra-low power hardware, generally powered by energy harvesting or capacitor, are needed to support the integration of intelligence into very small devices: biological implant, smart tattoo, RFC/RFID type solution, home automation, food and goods tracking, in-material health monitoring.

Next to the critical power issue, comes the *memory wall*. Today limitation is not coming from the pure processing power of systems but more from the capacity to bring data to the computing nodes in a reasonable power budget. As the memory dictates the size of the problem that can be solved, the needs to scale the application to the computing power requires a huge improvement in memory access time and this issue gets worse due to the fact that memory access time (typically a doubling of the bandwidth every 3 years) is lagging behind the progress made in CPU cycle time. Furthermore, the system memory challenge is only part of a broader Data Movement challenge which requires significant progress in the data access/storage hierarchy from registers, main memory (e.g. progress of NVM technology, such as the Intel's 3D-xpoint, etc.), to external mass storage devices (e.g. progress in 3D-nand flash, SCM derived from NVM, etc.). In a modern system, the major part of the energy is dissipated in moving data from one place to another: computing in memory, or decreasing the communication cost between the storage and where the data are processed, is crucial. Another important point is the emerging a new memory technology (PCM, MRAM, ReRAM, …) with access performances which are much better than standard flash memories but not yet at the level of DDR. This allows new application partitioning between volatile and non-volatile memory and more generally a complete revisit of the system memory hierarchy. This is very important especially regarding energy saving policies. One of the main interest is the capacity to change from one operating point

---

CPU:http://wccftech.com/intel-skylake-cpu-10-20-performance-boost-faster-igpu-ddr4-overclocked/

Memory:https://www.intel.com/content/www/us/en/architecture-and-technology/intel-optane-technology.html

Interconnect: http://www.infinibandta.org/content/pages.php?pg=technology_overview

Storage:http://www.zdnet.com/article/ibms-world-record-330tb-uncompressed-data-on-a-palm-sized-tape-cartridge/

to another very rapidly in any case much faster than saving an execution context from DDR to Flash as it the case today. This opens a path to very aggressive energy saving policies as the latency as the switch from one mode to another can be extremely short. As a consequence, it drives needs in the Application frameworks to integrate these new capabilities in order to give application developers the capacity to use these new features.

Finally, the increasing size and complexity of such system architectures is challenging their design and development, implying in turn the revision of their *design methodology* (see chapter 11 for more details).

The software challenges

The choice of a computing solutions is not mainly driven by its intrinsic performances, but by the software ecosystem. With the ever-increasing complexity of processors, more advanced Software infrastructure has to be developed.

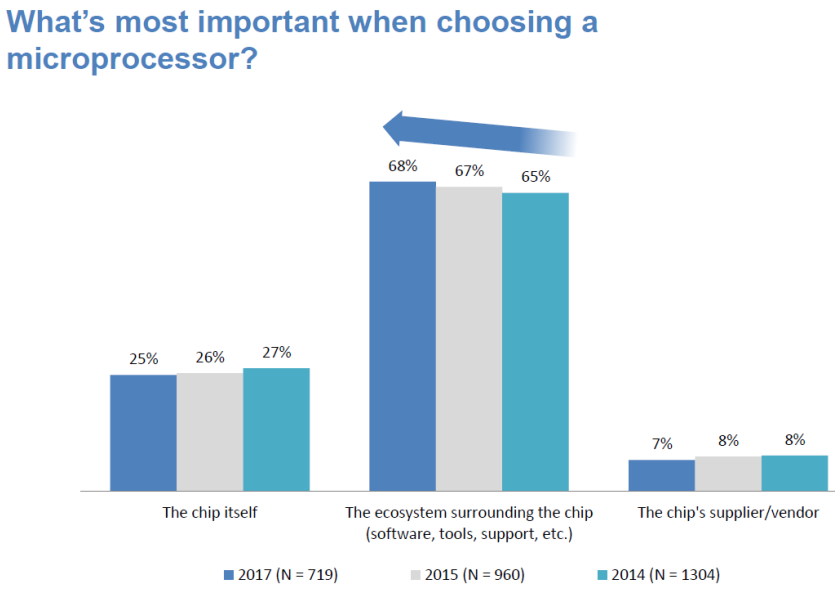


Figure 40 - Source: AspenCore 2017 Embedded Markets Study

It is well known that the gap between hardware and software capabilities is widening in high-performance systems. While a single processor chip can provide several cores up to thousands of processing cores, many applications still (sometimes poorly) exploit only few cores in parallel. Safety Critical applications hardly start to use multi-core processors. Therefore, there is an urgent need to upgrade the software to the hardware capacity through the following potential actions:

- Middleware/Software: the data movement constraints (streamed, stored and even replayed from stream) must be used to dynamically or statically schedule massively parallel tasks in order to optimize the cores usage. This scheduling strategies need not only to optimize processor usage, but also prevent any data loss and enforce processing latencies. Guaranteeing both real-time and safety properties will come from a close collaboration between hardware and software, where time is frequently absent from the underlying programming language. For HPC, coordinated and hierarchical checkpoint/restart new strategies become mandatory to unload this burden from application level to move into system level and to manage optimally heterogeneity.
- Programming Models and Methods: *Massively and Hybrid Parallel Computing* requires new programming models suitable to support scalability and a large range of heterogeneous computing, such as for vector accelerators. The main challenge is to have programming models integrating multi-dimensional constraints. Up to now the programming models have been mainly based on maximizing the efficiency of the computing system regarding the type of data and their type of use case. Now

things are different as this optimization still needs to happen but other aspects have to be managed simultaneously such as power consumption, scalability security, and dependability. This is even more important for IoT system where resources are very scared and for which efficient resources management is a very differentiating factor. One of the challenge is to provide application designers with the right knobs in order to make the best tradeoff. This is a strong need for new languages or programming framework where this security, dependability, power consumption are built-in features with an adequate control given to the programmer in order to ensure the most optimal solution in term of design decisions. It is mandatory to offer the best expertise in every domain even for developers which are not the best experts in all the dimensions of today's systems. This type of requirement is ranging from very small IoT device up to very large computing systems.

- This requirement necessitates in turn the definition of common communication protocols (e.g. CCIX, Gen-Z, OpenCAPI) and the improvement of existing standard (e.g. PThreads/OpenMP, OpenCL, OpenACC, CUDA, HLS, MPI, auto-vectorization, etc.) to provide better support for both fine-grained and coarse grained parallelism, interoperability, scalability, portability, latency-awareness.

The application complexity is rising dramatically and represents a challenge for their optimization. Improvement of existing codes is just impossible which implies the invention of new parallelization strategies. The development of such massively parallel applications requires in turn new tools to support the debugging, validation and certification tasks.

In addition, the software should also contribute to the solution of hardware critical challenges (Cf. §3.1.3.1) by providing robust, energy-aware and fault-tolerant, self-healing applications.

System challenges and applications/architecture co-design

The upcoming computing systems (IoT, CPS, HPC, etc.) cannot be a mere assembly of disparate improvements issued from the previous steps but a smart combination of them to provide efficient solutions. That leads to the concept of software/hardware *co-design* challenge which can be defined as the simultaneous design/development of both hardware and software to optimally implement in a desired function. The high-level approaches are shown in chapter 11, but the complexity of co-design of computing and storage stems from the combination of the following themes of work:

- Reconsideration of basic mathematical models and reworking of algorithms (e.g. massively parallel algorithms, genetic programming, etc.); they have to remain platform-independent to suit any future candidate targets. Algorithms that a priori include sequential sections have to be restructured to open ways to extract as much inherent parallelism as possible through suited state-of the-art tools to cope with the capabilities of the computing fabric,

- Scalable implementation on large and heterogeneous platforms (different compute architectures, accelerators, etc) using new interoperable and composable programming paradigms (energy-aware static/dynamic placement, scheduling, communication, etc.) that can be transparent to the user
- Optimal composition of hardware and of the constraints of users according to many variable criteria including computing technologies, use of reconfigurable logic, memory access and interconnection and I/O (e.g. combination of communication protocols, support of data coherence/consistency models, memory and network contention etc.). It yields a design space exploration problem that we are able to face with appropriate tools. This huge complexity will be managed by selecting only some relevant solutions that match the user multi-criteria. This kind of tooled-up approach enables to properly size future products

14.3.1.5. EXPECTED ACHIEVEMENTS

HPC and related application domains

As said in previous sections, HPC becomes indispensable to all branches of government, education and all fields of industry and thus it impacts almost every aspect of daily life. Until this day, the progress towards petascale computing was achieved mainly through an evolutionary enhancement of microprocessor technology but the transformation towards the next step of exascale computing represents a challenging venture: an in depth reworking of application codes in conjunction with radical changes in hardware to optimally exploit high levels of parallelism in solving ever increasing complex problems.

The HPC technology will in turn extends itself into a set of immediate application areas including Data Center, Cloud Computing and offers a convergence with Big Data to form the new *HPDA* (“high-performance data analytics”) discipline.

And the technologies developed for HPC generally become mainstream few years after: self-driving cars required a processing power of super-computers of few years ago, if is the "ripple down effect".

CPS domain

More and more heterogeneity is the way to reach the performance expected from CPS with always more energy efficiency. Considering that the use of multi-core processor is not yet fully managed for safety critical application, for which determinism is mandatory, adding heterogeneity is just moving to another order of complexity. Current programming solution for dedicated accelerator, even if promising such as High Level Synthesis for FPGA, relies too heavily on the programmer being able to understand the underlying architectures. The advent of FPGA as part of Cloud building blocks, such as F1 Amazon EC2, and Microsoft Brainwave dedicated to Deep Learning, will accelerate the development of scalable, hardware-agnostic and energy efficient programming solutions. Such solutions must encompass FPGA, DSP, GPU, CNN/DNN Accelerator, or even more innovative hardware.

Distributed intelligent platforms will be part of the landscape of every-day life activities (healthcare, transportation, education, business, etc.) to reduce the event-response latency by providing real-time decisions, capturing live data streams, building complex decision logic and enabling real-time monitoring, predictive alerts and guided interactions

Extreme low power and IoT

Extreme low power computing is necessary in many advanced systems based on pervasive computing, including sometimes devices where computing is necessary but no battery is available. Beyond the challenge of harvesting energy, there is a pressing need for architectures fully optimizing the energy consumption with dedicated processing cores, accelerators and energy management systems.

14.3.2. Making computing systems more integrated with the real world

Dependability and real time

14.3.2.1. VISION

Computing systems are more and more pervasive and they are present in almost all objects of current life (wearable objects, home appliances, retail and home automation, etc.). These systems bring intelligence everywhere (smart anything everywhere) and are usually named Cyber-Physical Systems. Their role in complex systems is becoming increasingly necessary (in cars, trains, airplanes, health equipment, etc.) because of the new functionalities they provide (including safety, security, autonomy). They are also required for the interconnection and interoperability of systems of systems (smart cities, air traffic management, etc.).

Because of their close integration with the real world, they have to take into account the dynamic and evolving aspect of their environment, to provide altogether deterministic, high performance and low power computing as well as efficient processing of deep learning algorithms.

Finally, because of their usage in dependable systems they have to follow certification / qualification processes imposing guarantees regarding their functional and non-functional specification.

14.3.2.2. SCOPE AND AMBITION

The ambition for computing systems when they need to be integrated in the real world is the realization of systems offering altogether a large computing local performance (since they need to be smart), a good level of performance predictability (implying deterministic architecture suited to certification/qualification processes) and efficient interconnection capabilities (distributed systems and systems of systems).

To interface with the physical world, these CPS require a fine, fast and dynamical understanding of their environment through real-time analysis base on AI technologies.

Their natural interconnectivity requires establishing connections towards the external world with high grades of safety and security. Moreover, the realization of trustable computing systems ensuring reliability, predictability, safety, surety and privacy is generally necessary, even when connected to systems and networks that have low security, safety, or reliability levels.

Engineering methods (including analysis, verification and validation to ensure properties such as security) scaling with the complexity and high-level non-functional requirements of CPS are necessary especially in the case of adaptive systems. They must satisfy the multidisciplinary challenge of designing CPS with numerous constraints, objectives and functional or non-functional requirements which are often contradictory (response time, safety, trust, security, performance, QoS, energy efficiency, size, reliability, cost).

14.3.2.3. COMPETITIVE SITUATION AND GAME CHANGERS

Europe has a good position on smart systems connected to the real world.This strong position is confirmed at products level (cars, planes, industry, robots, etc) as well as scientific level (formal methods, time analysis, design methodology) and general know-how in embedded systems.

However, as this domain is undergoing tremendous changes (due to the increased need for more computational resources) it remains a great opportunity for future developments. The good technological level of Europe must be maintained and improved.

14.3.2.4. HIGH PRIORITY R&D&I AREAS

System challenges and applications/architecture co-design

As explained in the previous challenge, computing in embedded systems faces fundamental challenges of power, bandwidth, and synchronization.

But **dependability** is a key for these embedded systems which are the heart of systems used by people (planes, self-driving cars, etc). Knowing how to correct errors on these more and more complex systems is a challenge to make them reliable and resilient. Knowing how to ensure that time constraints (response time, etc) are met is a challenge to make them predictable, and thus safe. Security techniques (secure access mechanisms, block chains, etc) have to be adapted to make CPS able to satisfy the privacy of their users.

Because of their interaction with the physical world CPS have extremely dynamic properties with numerous parameters possibly changing at run time, sometimes discontinuously. The subsequently high number of scenarios makes their modelization, simulation and implementation really challenging.

CPS tend to offer an increased autonomy (autonomous cars, robots, home automation, etc.) which imply complex decision making based on AI combined with high timing constraints as well as reliability, safety and security constraints.

This challenge of dependability is also present for HPC and server systems: as the number of components increases faster than their reliability, *system resiliency* becomes the third challenge pole in Exascale system design: SMTBF is decreasing towards the range of 1h-10h and thus requires more efficient checkpoint/restart mechanisms together with Algorithm-Based Fault Tolerance, redundancy strategy, enforcement of real-time constraints for application reconfigured at runtime, real-time vote with no single point of failure. Technical improvements on this topic is expected to be manifold to include enhancement of both hardware and software reliability but also the development of fault resilient algorithms.

The hardware challenges

Today's distributed embedded systems (as exemplified by CPSs) are built on a large number of distributed computational platforms which communicated with each other via a [wireless] network fabric and interact with the physical world via a set of sensors and

actuators. To meet the increasing performance and flexibility demands, embedded systems leverage heterogeneous multi/many-core architectures optionally enhanced with hardware accelerators (e.g. GPU) to replace more and more µcontrollers and DSPs, to ensure real-time behavior with partitioning and virtualization technologies and to handle critical systems (e.g. independent certification of safety-critical components, separation of safety-relevant subsystem on the same processor, etc.).

Determining statically the Worst-Case Execution Time of such a complex system is an intractable challenge, and new (possibly dynamic) approaches are required to ensure that the system will fulfill its mission in due time. Processing time determinism is indeed often required in applications with safety critical or hard real-time constraints. The solution can also be found with the design of dedicated architectures. When this is affordable, specific interconnection systems for multi/many-core processors can for instance be more effective and easier to implement than software approaches.

For the security aspect, trustable secure zones, enclaves, isolation techniques, specific modules for protection, cryptoprocessors, etc, have to be considered. The Open Source hardware (RISC-V, OpenPower, etc.) will allow white box design and the exploration of processor architectures by the community. Specification of many parts of the systems are generally not completely known or disclosed. This leads to black or grey boxes which have to be specifically considered. With most recent technologies, components reliability or performance variation may also require a specific approach to ensure good characteristics at upper layers. Edge systems are already made of small processing (such as µcontroller) cooperating altogether (e.g. watch, phone, shoes). The battery requirement limits the possibility of integration. With the advent of autonomous energy sources, such as ambient RF energy harvesting, the design of ultra-low power and energy aware processor for computation and communication may greatly improve this integration.

The software challenges

Software components are distributed throughout an embedded system and interact with one another across well-defined interfaces. At a feature level, they also collaborate via their shared interaction with the physical world. Two specific challenges are particular to collaborating embedded systems:

- Virtual System Integration: From a design perspective, challenges arise in the modelling (integration of models representing different formalisms, communication among hardware/software sub-models, etc.) and analysis of the design.
- Runtime System Adaptation: Reasoning and planning adaptation of a set of subs-systems via the maintenance of consistent information and management of inconsistencies and the usage of online model calibration.

Getting computers to work together with physical processes requires technically intricate, low-level design: Embedded software designers are forced to deal with interrupt controllers, memory architectures, assembly-level programming (to exploit specialized instructions or to precisely control timing), device driver design, network interfaces, and

scheduling strategies. The most critical systems (mission critical or even life critical) require a high verification level which can only be reached by a combination of formal methods and accurate timing analysis, trace analysis, monitoring with dedicated control algorithms, accurate profiling solutions, etc. The dynamicity of CPS implies to consider systems in which the state space cannot be explored at design time. In spite of great progresses in that domain, the end-to-end verification of complex hybrid systems is still a challenge. There is also a significant advantage to perform numeric stability property verification through formal methods of these systems. Improving trade-off between communication availability, autonomy and real-time requires tightly cooperating hardware, platform, programming model (moving from task to event based) and application software.

14.3.2.5. EXPECTED ACHIEVEMENTS

The expected achievements on this part of computing are to provide key development platforms and building blocks (hardware and software) to enable the design of trustable cyber-physical systems.

Moreover, “de facto” European standards for interoperable CPS systems will be a strong benefit to foster the development of competitive European product in that domain.

14.3.3. Making "intelligent" machines

Towards autonomous systems

14.3.3.1. VISION

Artificial Intelligence (AI) became again a very hot topic recently, mainly due to the practical success of Deep Learning on image classification, voice recognition and even in strategic games (AlphaGo from Deepmind/Google becoming the best Go player). According to the "Hype Cycle for Emerging Technologies, 2017" by Gartner, Smart Robots, Virtual Assistants, Deep Learning, Machine Learning, Autonomous Vehicles and Cognitive Computing at the peak of the curve, while Artificial General Intelligence, Deep Reinforcement Learning and Neuromorphic Hardware are still on the rise. According to a report from Tractica (see Figure 41), the revenues generated from the direct and indirect application of AI software will grow from $1.4 billion in 2016 to $59.8 billion by 2025.

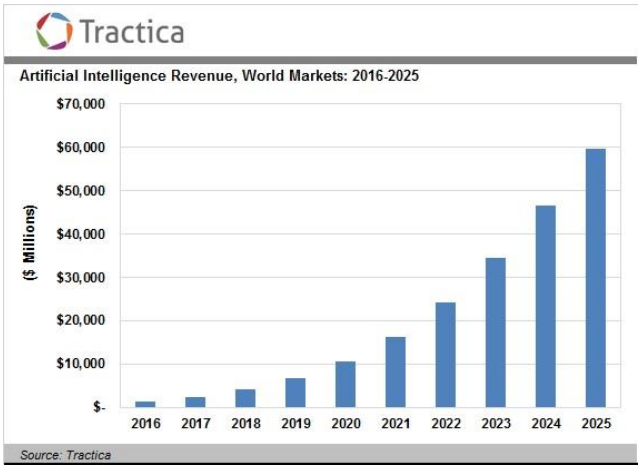


Figure 41 - Forecast of AI revenues until 2025

These techniques will be big technological shift, and will have an overall impact. In the domain of Computing and storage, they will have two consequences:

- Europe should remain in the AI race and develop efficient solution for IA systems, both at the hardware and software level. AI, and more especially Deep Learning, requires large amount of computation (in the exaflop range) for the "learning" phase, and embedding AI solution in edge devices will require low energy accelerators. As previously seen, Europe's place in CPS systems should drive it to the lead position in Autonomous Cyber-Physical Systems, adding "intelligence" to CPS.
- AI techniques can be used for the design of computing solutions, e.g. for selecting an optimal hardware combination (generative design), or for software generation. There are already researches using Deep Learning for generating Deep Learning networks…
-

14.3.3.2. SCOPE AND AMBITION

AI and especially Deep Learning require optimized hardware support for efficient realization:

- For the learning phase, the large amount of relatively low precision computations (e.g. float16) required accelerators with efficient memory accesses, and large multi-compute engine structures. Access to large storage area is necessary to store all the examples that are used during this phase,
- For the inference phase (e.g. on the edge), it will require low power efficient implementations with computation and memory closely interconnected.
- New emerging computing paradigm, using unsupervised learning like STDP (Spike-timing-dependent plasticity), might change the game by offering leaning capabilities at relatively low hardware cost and without the need to access a large

database. Instead of being realized by ALU and digital operators, STDP can be realized by the physics of some materials, such as the ones used in Non-Volatile Memories. This could differentiate Europe from the learning accelerators for servers and HPC which require a huge investment, and solutions are already available, either open or closed, such as the NVIDA Volta GPU, Google's TPU2, etc.

Developing solution for IA at the edge (e.g. for self-driving vehicle, personal assistants and robots) is more in line with European requirements (privacy, safety) and knowhow (embedded systems).

Europe should be also at the forefront for emerging hardware and software solutions for AI, beyond classical Deep Learning, particularly, in the use of AI-based solution to improve the development of systems, by selecting optimal solutions to complex problems, in various domains, including development of new computing solutions.

Finally, hardware and software should be developed to support Self-X systems (self-repairing, analyzing, managing, …) to ensure more dependable systems.

14.3.3.3. COMPETITIVE SITUATION AND GAME CHANGERS

AI techniques could change the way we interact with computer: instead of programming, i.e. telling the machine how to do things by giving it a list of instructions, we might move to a more declarative or parenting approach where we tell the machine what should be done (and not how it should be done), e.g. through examples. Typical computing models with be complemented with these new ones.

On the user's side, AI techniques will allow to have more natural interaction, e.g. with language, and AI techniques will be key for machine to recognize and analyze its environment, e.g. for self-driving cars. For safety, privacy and cost (reduction of the communication bandwidth with server), local intelligence (intelligence at the edge) need to be developed, working harmoniously with the cloud, but exchanging data with it only when required. This will require more efficient processing capabilities at the edge, and increase of local storage. In the coming years, the processing capabilities of the IBM Watson used for winning the jeopardy game could be affordable as home server, and the compete Wikipedia encyclopedia will fit in its local storage. Dedicated accelerators for Deep Learning and related techniques will allow to develop autonomous robots, intelligent personal assistant, safety systems and autonomous vehicle with minimum need for accessing extra computing resources and storage.

Currently, IA and Deep Learning are mainly developed by the extended GAFA (Google, Amazon, Facebook, Apple, Microsoft, Baidu) and they make large investment in this domain by acquisition of major players (both start-ups and known academics). They also have in-house the large databases required for the leaning and the computing facilities (even if they develop accelerators by themselves, for example Google and Apple). US and Chinese government also started initiatives in this field to ensure that they will remain preeminent players in the field.

It will be a challenge for Europe to be in this race, but the emergence of AI at the edge, and its how-how in embedded systems might be winning factors.

14.3.3.4. HIGH PRIORITY R&D&I AREAS

System challenges and applications/architecture codesign

As previously seen, managing the complexity of computing systems is an important challenge, and IA inspired techniques can be used to design more efficient hardware and software systems. Analyzing the large space of configurations, and selecting the best option with clever techniques allows to design more efficient systems, taking into account a large number of parameters. It is still a research area, but in mechanical design it is already at the product level (*generative design* tools).

There are already experiments in this field to design efficient multi-core systems or generate more efficient code.

Techniques for self-analyzing, self-configuration, discovery of the features of connected systems, self-correcting and self-repairing are also domains that need to be developed to cope with the complexity, interoperability and reliability of computing and storage systems.

The hardware challenges

To support efficiently new AI related applications, both at the server and client (edge side), new accelerators need to be developed. For example, Deep Learning don't need full precision floating point for its learning phase, only 16 bit floats are required. But a close connection between the compute and storage parts are required (Neural Networks are an ideal "compute in memory" approach). Storage also need to be adapted to support IA requirements (specific data accesses, co-location compute and storage), memory hierarchy, local vs cloud storage.

Similarly, at the edge side, accelerators for AI applications more specifically real time inference will be required, especially to reduce the power consumption. For Deep Learning applications, arithmetic operations are simples (mainly multiply-accumulate), but they are done in very large number and the data access is also challenging (also clever scheme are required to reuse data in the case of convolutional neural networks or in system with shared weights). Computing and storage are deeply intertwined. And of course, all the accelerators should fit efficiently with more conventional systems.

Finally, new approaches can be used for computing Neural-Networks, such as analog computing, or using the properties of specific materials to perform the computations (although with low precision and high dispersion, but the Neural Networks approach is able to cope with these limitations).

Over the years, a number of groups have been working on hardware implementations of deep neural networks. These designs vary from specialized but conventional processors optimized for machine learning “kernels” to systems that attempt to directly simulate an

ensemble of “silicon” neurons, known as neuromorphic computing. The latter neuromorphic systems are more in line with what researchers began working on in the 1980s with an architecture which is modelled after biological neurons.

Recent achievements in this field are:

- the biologically inspired chip “TrueNorth” from IBM that implements one million spiking neurons and 256 million synapses on a chip with 5.5 billion transistors, and
- the neuromorphic chip developed by IMEC, capable of composing music by learning rules of composition (http://magazine.imec.be/data/83/reader/reader.html#!preferred/1/package/83/pub/89/page/5).
- The Neuram3 H2020 project, which just delivered a prototype chip with better performances than TrueNorth

Besides Deep Learning, the “Human Brain Project”, a H2020 FET Flagship Project which targets the fields of neuroscience, computing and brain-related medicine, including, in its SP9, the Neuromorphic Computing platform SpiNNaker and BrainScaleS (https://electronicvisions.github.io/hbp-sp9-guidebook/). This Platform enable experiments with configurable neuromorphic computing systems.

In the U.S. a report of a roundtable “Neuromorphic Computing: From Materials tot Systems Architecture” of 2015 (https://science.energy.gov/~/media/bes/pdf/reports/2016/NCFMtSA_rpt.pdf) describes, amongst others, the need for Neuromorphic Computing and identified a number of open issues ranging from materials to systems. Early signs of this need appear with the emergence of machine learning based methods applied to problems where traditional approaches are inadequate. These methods are used to analyse the data produced from climate models, in search of complex patterns not obvious to humans. They are used to recognize features in large-scale cosmology data, where the data volumes are too large for human inspection.

The software challenges

The paradigm introduced by new AI techniques such as Deep Learning could promote more emphasis on *declarative* instead of imperative programming, "programming" by examples, where goals and constraints are given, but he system should determine by itself the best way to reach the goals. How this approach can be combined with "classical" systems, how to ensure that the solution is correct, etc, are new challenges. Validation, verification of systems, and the ethical questions posed by systems that will determine themselves their choice in a more or less transparent way are also important challenges. This is also part of the more general challenge describe in the previous challenge consisting on determining if a complex system, composed of white (we know the internals, how it works), grey (we know the specifications and interfaces) and black (we don't know how it works) boxes, will ensure the Quality of Service and objectives for which it has been designed.

The problem of interoperability and the complexity introduced with the new accelerators and how they can be combined with classical systems need also to be solved.

14.3.3.5. EXPECTED ACHIEVEMENTS

In the domain of system challenges and applications/architecture codesign, the expected achievement is to provide a platform and tools that allows to manage the complexity of systems and to design efficient solutions with the help of AI related techniques. It should help the partitioning of tasks onto various hardware and accelerators (including those for Deep Learning). Europe should be leader in generative design tools for designing computing systems.

From the hardware point of view, new efficient accelerators for AI tasks should be developed for edge processing, allowing to embed intelligence near the user and limiting the use of remote accesses to ensure safety, privacy and energy efficiency.

From the software side, existing software environments should be extended to support declarative programming, and a good coordination with AI related approaches, allowing a smooth integration of various approaches.

A European run-time ensuring self-analyzing, self-configuration, discovery of the features of connected systems, self-correcting and self-repairing should be developed to become the “de facto” European standard for interoperable and reliable systems.

Solutions should be developed, both at the technical, ethical and legal level to ensure that AI related techniques will be accepted in the society, with focus on ensuring that the objectives and Quality of Service are correctly ensured.

14.3.4. Developing new disruptive technologies

Moore’s Law has started to break down as the size of transistor has shrunk down to near the atomic scale and alternative ways are investigated to get more computing power, including quantum computing, neuromorphic computing, biochemical computing, etc. for the longer term.

In the US alternative approaches to computing are gathered under the name “Reboot Computing” including all aspects from materials and devices up to architecture. As it is not possible to cover all the different approaches explored on computing in this SRA due to space limits, a few of the promising approaches are selected as examples, but with the clear message that Europe should remain to invest to keep on par with the rest of the world.

14.3.4.1. QUANTUM COMPUTING

In 1982, R. Feynman sketched out roughly how a machine using quantum principles could carry out basic computations and a few years later, David Deutsch outlined the theoretical basis of a quantum computer in more detail. Thanks to a large spectrum of follow-up research, it is nowadays known that Quantum Computing can theoretically contribute

significantly to the resolution of problems hard-to-be-solved by classical computing (e.g. Factoring, Cryptography, Optimization, etc.). To move these algorithms from blackboard to concrete realization, two main aspects require attention. The first one is the need for a complete, scalable quantum computer. Indeed, if during the last three decades, quantum computing has progressed to proof-of-concept demonstrations of single- and multi-unit qubits (photons, electrons, quantum dots and other approaches), it is very much at the research stage with scientists competing on the manipulation of a handful of qubits. The second aspect requiring attention is the development of a unified set of methodologies and techniques to use and interact with such a physical quantum machine: at the logical level, how do we encode and test quantum algorithms? The lack of efficient general-purpose quantum computers (e.g. the D-Wave 2000Q System oriented towards Quantum Annealing) lead to a variety of meet-in-the-middle approaches by major actors, with the development of a variety of software-based emulators – including Atos/Bull Quantum Learning Machine, Microsoft's LIQUi|>, Google's Quantum Computing Playground - to assist in the research and development of quantum algorithms, independently from the hardware research activity. One thing can be learned from these approaches: A good computational paradigm for quantum computation is that of a quantum co-processor linked to a classical, conventional computer. Pre- and post-processing are done classically while the quantum co-processor targets the quantum-specific aspects of the computation. This will pose new challenges:

- There is no well-defined model of computation mixing classical and quantum computation, nor a complete compilation and software stack.
- The interfacing between the classical computer and the quantum computer will require new developments, both for the bandwidth, the errors and the fact that quantum machines currently works at very low temperature, where behaviour of classical electronics is not well defined.
- The instability of quantum states, and interferences, will lead to errors, and error correction is therefore a challenge.

14.3.4.2. NEUROMORPHIC COMPUTING

Neuromorphic computing is part of the previous challenge "Making "intelligent" machines, and is detailed in the part concerning the hardware challenges, but it has also its place here because in can be performed with different computing elements than ALUs and binary coding. For performing its operations, the information can be coded not only in spatial way (like in binary code), but in a spatial and temporal way: for example, with "spikes" – the pulses similar to the ones that carry information in the brain – where the moment of emission of the pulse is an important element of the information. The processing can be done in an analog manner, or using the physics of specific materials, like for implementing the STDP learning rule. These materials, storing the information of the neural network in this "synapses", can be very small leading to very dense and low power realization of Neural Networks. Such realizations can be also compatible with the inference phase of Deep Learning approaches.

Reservoir computing can be seen as some kind of recurrent neural networks where only the parameters of the final output are trained, while all the other parameters are randomly initialized and where some conditions are applied. It can be implemented with optoelectronics[39].

14.3.4.3. OPTICAL COMPUTING

Optical computing has been an active topic of research for over some decades, has not become mainstream, but is also still alive today. Not only university groups study the issues of optical computing, in either hybrid or pure optical solutions, but also companies are still on this track. One example is Hewlett Packard Labs who designed an all optical chip that features 1052 optical components to implement an Ising machine

(see: http://spectrum.ieee.org/semiconductors/processors/hpes-new-chip-marks-a-milestone-in-optical-computing). This chip demonstrates that advances in all-optical information processing, including digital and analog, classical and quantum, and those based on Turing computation are still being made.

We refrain from describing all possible and different approaches to optical computing in detail, as there are quite many, but it is clear that the topic is not dead and deserves to be considered as an alternative implementation to computing with far reaching consequences. Although some considered the field of optical processing to have passed its peak, the 2010s have since seen a clear resurgence in activity, around new approaches in quantum and analogue mesh and phase-based computing.

14.3.4.4. SCOPE AND AMBITION

Shrinking transistors have powered 50 years of advances in computing, but now, for both technical and financial reasons, other ways must be found to make computing more capable. What's next will be more exciting : Several new emerging technologies are expected to be available within the next five years : Quantum computers, which have the potential to be millions, of times more powerful than current technology and neuromorphic computing, which provides chips with thousands of times more efficient than current technology (see previous challenge).

14.3.4.5. COMPETITIVE SITUATION AND GAME CHANGERS

Even for those new emerging technologies, the starting line is not the same for all actors and hence a levelling in terms of investment is necessary in order to catch up with the original delay.

[39] L. Larger, M. C. Soriano, D. Brunner, L. Appeltant, J. M. Gutierrez, L. Pesquera, C. R. Mirasso, and I. Fischer, "Photonic information processing beyond Turing: an optoelectronic implementation of reservoir computing," Opt. Express 20, 3241-3249 (2012)

Europe is stating an action on quantum computing (a Flagship project) and a good synergy should be developed with ECS.

Concerning Neuromorphic Computing, Europe is still in the race, and the development of advance neuromorphic systems (and the supporting software and system integration) should be promoted and applied to industrial problems developed in this SRA, such as CPS au autonomous systems.

14.3.4.6. HIGH PRIORITY R&D&I AREAS

These new technologies require strong investments at all levels varying from hardware to software and integration with classical technologies. Indeed, in a first approach, they are considered as new accelerator technologies to be combined with classical computing in order to solve specific classes of problem. The best strategy is still to adopt a "meet-in-the-middle" approach, working on many aspects (software, hardware, integration, algorithms) of those technologies at the same time until converging to exploitable solutions.

14.3.4.7. EXPECTED ACHIEVEMENTS

It is expected to produce in a time interval of 5 years new acceleration solutions from those emerging technologies to be integrated with classical computing platform in order to support effectively specific industrial problems.

14.4. Make it happen

14.4.1. Educational Challenge

For both the medium (2020) and long (beyond) terms, the [r]evolution in computing requires a complete flattening of methods and techniques in hardware design (scaled up architecture, heterogeneity, size, etc.) , software development (massive parallelism, new concepts, etc.) and applications (new modelling, mathematical background). This creates in turn grand challenges in computing education in order to provide skills and competencies for the next generation of computing.

14.4.2. Organize the community in Computing

It is important to organize the computing community, and increase the exchanges between the application owner and computing and storage specialist, in order to actively drive the innovation. Inside the computing community, synergies should be increased between the High-Performance computing and Embedded system communities, and also between the compilers and tools and the hardware architects. There are initiatives in that field, mainly carried by CSA (Coordination and Support Action).

14.4.3. Standardization

For the medium terms, standardization is on smart interfaces, communication protocols and programming models to support heterogeneous architectures and massively computing. For emerging technologies such as quantum computing and neuromorphic computing, standards are still to be defined and adopted by the computing community.

14.4.4. Foreign export restriction

Export restriction can be a roadblock to make and sell European computing systems. Some key non-European components can be restricted or forbidden to re-export to some countries, even if the product using them is made in Europe. It is therefore a drive to have European technology for those components, which will give to European companies more freedom in the availability of key components and markets. US Export restrictions (one of them is ITAR, see annex), were at the origin of the development by China of its own processor and HPC machine, which was at the top of the top500 in 2017.

14.5. Timeframes

The following table illustrates the roadmaps estimated for computing and storage.

Challenge	Topic	2017	2020	2025	2030
Computing Performance	HPC	Peta Computing $n10^5$ cores, xPB memory 10-15 MW		Exascale Computing $n10^6$ cores, xEB memory 20-30 MW	
System Integration	CPS	Integrated Computing (MPSoc, $n10^2$ cores) Expanded Autonomy Security Architectures		Autonomous Architectures ($n10^3$ cores) Adaptable Systems	Pervasive Computing
		Design Methodology Feedback Systems CyberSecurity		Edge Computing	
Disruptive Technologies	Quantum Computing	Simulation/Emulation (5-50 Qubits)		Universal Quantum Computer	
	Optical Computing	160PF, 640Pb/s, 11pJ/bit		10EF, 40 Eb/s, 250 FJ/bit	
	Neuromorphic Computing	4.00E+09 Neurons 1.00E+12 Synapses 4KW		1.00E+10 Neurons 1.00E+14 Synapses 1KW	

Figure 42 - Computing and Storage roadmap

15. Electronics Components & Systems Process Technology, Equipment, Materials and Manufacturing

15.1. Executive summary

Technological challenges arise from future technologies such as Internet of Things, Big Data, 5G and beyond networks and Industry 4.0. These challenges require advances in Moore's Law (More Moore, MM), in additional functions (More than Moore, MtM), in optimization of existing technology nodes, and in integration and manufacturing schemes, well into the next decade.

Furthermore, the European industry in sectors such as healthcare, automotive, energy, smart cities and manufacturing strongly depends on the timely availability of highly specialized electronics devices enabling added value and new functionalities in their products.

Independent access to semiconductor technology for manufacturing of function-critical Electronics Components and Systems (ECS), and their development and manufacturing in Europe are indispensable for meeting the challenges of the European society.

ECS manufacturing in Europe requires access to advanced materials and equipment and competitive manufacturing techniques. The latter are a self-standing sector of European importance and forms the base of the ECS manufacturing value chain.

Consequently, the European position must be reinforced through leadership in all relevant technologies by driving the following Major Challenges:

- Developing advanced, logic and memory technology for nanoscale integration and application-driven performance;
- More than Moore and Heterogeneous System-on-Chip (SoC) Integration;
- Advanced smart System-in-Package (SiP) applications;
- Maintaining world leadership in Semiconductor Equipment, Materials and Manufacturing solutions.

15.2. 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 continental economy. The semiconductor equipment and semiconductor materials sectors employ in Europe more than 100 thousand individuals, the majority of them in high education level jobs. 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, increased employment and investments for innovative equipment, materials and for manufacturing of

semiconductor devices and systems through European leadership positions in MM, MtM and SiP.

Whilst the manufacturing of electronic components and systems faces strong competition from East Asia and the US, the European semiconductor and smart system industry is able to keep leading technological and commercial positions in domains in which Europa has an industry, for example in automotive, aircraft manufacturing, power generation and medical/healthcare. Goal should be to keep this industrial position. Europe can catch opportunities in these sectors for growth to provide electronic components and systems markets and help the European downstream industry to keep a leading global industrial position.

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 path to Cyber Physical Production Systems will significantly be enabled by the early availability of innovative semiconductor-, sensor and packaging technologies. Having a strong semiconductor portfolio "made in Europe" with early access for lead system suppliers is a winning competitive asset for Europe. The complete value chain must be covered to maintain the competitive situation of the European semiconductor process and integration technology. Ensuring the continuation of competitive manufacturing in Europe supported by a high level of excellence in manufacturing science and efficiency will enforce strong global positions of the downstream industry (security, automotive, aircraft manufacturing, power generation and medical/healthcare). It will 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.

Furthermore, through a traditionally strong and advanced educational system, and through the presence of world-leading research associations, Europe's R&D position throughout the whole stack of competences is remarkable.

15.3. Major Challenges

Making process, integration and packaging technologies for advanced smart ECS (Electronic Components and Systems), and corresponding advanced equipment and materials and manufacturing techniques available, will address the increased demand for miniaturization (repetition) and specialization. This enables a strong technology-design-system-application interaction.

The following Grand Challenges have been identified:

1. Developing advanced logic and memory technology for nanoscale integration and application-driven performance;
   As already evidenced in the latest versions of IRDS (International Roadmap for Devices and Systems), device density and switching speed are no more the single performance indicator for logic devices. Low power (stand-by and operational) and high operating temperature are of greater importance for European critical applications like Health, IoT and Automotive/Industrial.

2. More than Moore and Heterogeneous System-on-Chip (SoC) Integration;
   The realization of smart electronic components and systems for European critical applications requires complementing logic and memories with additional features, which are non-scalable with Moore's Law, to handle the functions of sensing, actuation, communication, data protection and power management. These heterogeneous functionalities can be integrated on the same System-on-Chip, such as for embedded memories, and for analogue and Smart Power, or realized as discrete components for SiP integration. Advanced technologies, processes and materials need to be developed for innovative More-than-Moore solutions. They enable innovative emerging applications, while leveraging synergies with processing and manufacturing technologies of More-Moore devices.

3. Advanced smart System-in-Package (SiP) applications;
   Advanced SiP technologies are required to deliver the functionality in meeting the demanding specifications and boundary conditions of major electronic component applications. The integration of more functionality in smaller volume requires new assembly and packaging materials, compatible chip/package interfaces, as well as heterogeneous integration of chips with different functionalities like MEMS/sensors, power chips, processors, or memory. Special focus must be on electrical capabilities and temperature constraints keeping robustness and reliability for the applications.

4. Maintaining world leadership in Semiconductor Equipment, Materials and Manufacturing solutions.
   Defend and extend Europe's world leadership positions in Semiconductor Equipment, Materials and Manufacturing solutions.
   Supply the European ECS manufacturing companies with 'best-in-class' equipment and materials, and flexible, agile and competitive semiconductor manufacturing solutions in the domains More Moore (MM), More than Moore (MtM) and System in Package, and by this the European application sector to compete on the world markets with top quality products.

15.3.1. Major Challenge 1: Developing advanced logic and memory technology for nanoscale integration and application-driven performance

Semiconductor process technology and integration actions will focus on introduction of materials, devices and new concepts, in close collaboration with the equipment, materials and modelling/simulation communities, to allow for the diversity of computing infrastructure needed.

The applications range 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 transistor level: (i) extensions of the scaled Si technology roadmaps (including FD SOI, FinFET/Trigate and stacked, Gate-All-Around horizontal or vertical nanowires, 3D integration), (ii) exploration and implementation of materials beyond Si (III-V, SiGe, Ge) and (iii) novel device, circuit and systems concepts for optimum power-performance-area-cost specifications, high energy efficiency and novel paradigms like neuromorphic computing. Long term challenges also include Steep Slope Switches (Tunnel FET, FeFET, NEMS) and spin-based transistors, and alternative materials (2D, CNT, Ferroelectric, Magnetic, etc.).

New memory concepts will be targeted to support the correct memory hierarchy in the various applications. An example is the opportunity to push new memory concepts (RRAM, PCRAM, STT-MRAM) to the demonstration level in the IoT infrastructure (from server, over edge to nodes). These alternative memories need the development of advanced novel materials (magnetic, phase-change, nanofilament). A much closer collaboration between device teams and system architects is indispensable in the future. New markets will require storage class memory to bridge the performance gap between DRAM and NAND. Internet of Things applications will require low power embedded devices and cloud computing with more mass-storage space. The standard memory hierarchy is challenged.

Simultaneously, advanced interconnect, SoC integration and packaging challenges will need to be addressed (cf also challenges 2 and 3), where innovative solutions to reduce the cost are required. 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.

In order to maintain the European competences in advanced design for integrated circuits and systems, a close link with a strong effort in semiconductor process technology and integration has to be maintained. Issues like the creation of standards for IoT, reliability for safety or mission critical aplications, security and privacy requirements need a close collaboration among all actors, to build leadership going forward in this coming generation of advanced and distributed computing infrastructure and diversified system performance.

Expected achievements

Maintaining competence on advanced More Moore technology in Europe to support leading edge manufacturing equipment development. Implementation of pilot-lines for specialized logic process and devices supporting European critical applications. Exploration of new devices and architectures for low-power or harsh environment applications.

15.3.2. Major Challenge 2: More than Moore and Heterogeneous System-on-Chip (SoC) Integration

This chapter covers More than Moore single chips (RF, bio, power, optical, etc.) and the integration of different functionalities like, CMOS logic, NVM, MEMS, Analog, power etc on a single chip. Depending on the application, advantages of heterogenous SoC technology can be size, cost, reliability, security and simpler logistics. Therefore, this technology is seen as a key enabler for the European industry. To maintain and strengthen Europe's position it is necessary to improve existing technologies and to integrate emerging technologies. All application domains addressed by the ECS agenda will benefit from components with very diverse functionalities.

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.

Semiconductor process and integration technologies for enabling heterogeneous functionality will focus on the introduction of novel (nano-)materials and advanced device concepts. A non-exhaustive materials list includes wide bandgap materials, III-V and 2D materials, organic, ferroelectric, thermoelectric and magnetic thin films, as well as packaging materials. At the functionality level, introduction of innovative RF technologies, integrated logic and embedded NVM, photonics, 3D integration technologies, power devices, MEMS and sensor systems are looked for. The driver for their integration is always a clear demand from the application domain. To maintain Europe's position, focus should be on 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. Further, early generation of models and their initial validation for benchmarking and IP generation are required. More specifically the following challenges are identified (non-exhaustive).

Digital functionality is specifically treated in section 7.1, but it is evident that Heterogeneous System-on-Chip (SoC) Integration will require specific solutions for the following challenges:

- Embedded Non-Volatile memories for smart functional devices
- Energy efficient computing and communication, including focus on developing new technologies, architectures, and protocols.
- Development of Ultra Low Power (ULP) technology platform and design.

Analogue functionality will be introduced in systems through:

- Integrated application-defined sensors technologies. With the recent success in mm-wave sensors and MEMS devices enabled by high volume semiconductor manufacturing capabilities in automotive and consumer applications (acceleration, radar, microphones, environmental sensors) the progress will be on further integration, miniaturization and packaging, surface conditioning, structuring and innovation in selectivity.
- New RF and mm-wave integrated device options, incl radar (building on e.g. SiGe/BiCMOS, FDX SOI, CMOS).

- Photonics-enabled device and system options.

Analogue functionality is a domain where process technology exploration for functional integration of novel materials (e.g. TMDs, Thermal- and Piezo electric, Ferroelectric, Magnetic, 2D materials and organics, e.a.) for various applications is essential.

Moreover, power devices for energy and power management as well as energy efficient components and systems are in high demand:

- 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; high voltage classes, lateral to vertical architectures
- Continuous research on performance, efficiency, power density and reliability aspects – either through further thinning of wafers, topologies and material compositions
- Energy harvesting, micro batteries, supercapacitors and wireless energy.

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. Special focus should be on chip-package interaction, e.g. with respect to stress, EMC, temperature and application specific environmental integrity.

Manufacturing specific elements for the More than Moore and Heterogeneous System-on-Chip (SoC) Integration requires specific focus:

- Cope with high volumes and high quality (for e.g. power semiconductors, sensors and MEMS devices)
- Enable flexible line management for high mix, and distributed manufacturing lines
- Productivity enhancements (e.g. wafer diameter conversions) for MtM technologies to significantly improve cost competitiveness

It will also require adapting factory integration and control systems to adopt industry 4.0 principles to manufacturing environment in Europe, a clear area for synergy with the manufacturing challenge in this agenda.

Expected achievements

Implementation of pilot-lines for integrated application defined sensors, including packaging, the same for new RF and mm-wave device options including radar, photonics options as well as packaging solutions and power electronics. Initiation of the creation of Process technology platforms for biomedical devices for minimally invasive healthcare applications and packaging. Exploration of functional integration of novel materials.

15.3.3. Major Challenge 3: Heterogeneous System-in-Package (SiP) integration

This chapter covers the integration of chips of different functionalities like, CMOS logic, NVM, MEMS, Analog, etc into a SiP. Depending on the application heterogenous SiP technology can provide a better compromise between functions available, performance and time to market.

Therefore, this technology is also seen as a key enabler for the European industry. To maintain and strengthen Europe's position it is necessary to improve existing technologies and to integrate emerging technologies. All application domains addressed by the ECS agenda will benefit from innovative system-in-package components.

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

Compared to chip technology, assembly and packaging are becoming more important. Today in many cases assembly and packaging costs are higher than the chip cost. To tackle this trend, we must focus on SiP process technologies that take into account all the level; chip, package and board/system, and find the optimum trade-offs between function, cost, power, reliability, etc.

To remain economically sustainable and globally competitive a toolbox must be setup which includes process technologies that provide cost-effective and outstanding system-in-package integration, such as 3D interconnect technologies, fan-out technologies. …..

As for System-on-Chip integration, due to the miniaturization and increasing functional density of SiPs, it is important to consider chip package interaction, e.g. Power, Thermal, Mechanical, Stress, EMC, etc. In addition, the interfaces to the system/board need to be considered. For example, a MEMS device which requires a carefully designed package for optimum performance.

At macro-scale level, a system can be seen as consisting of a collection of large functional blocks. These functional blocks have quite different performance requirements (analog, high voltage, embedded non-volatile memory, advanced CMOS, fast SRAM, ...) and technology roadmaps. Therefore, for many applications 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 assembled parts using 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 having a different vertical interconnect density. Different technologies are therefore required at different levels of this 3D hierarchy.

Research and development priorities are on:

- Innovative interconnect technologies, that allow vertical as well as horizontal integration. This includes process technologies for vertical interconnects like Through Silicon Via (TSV), Through Encapsulant Via (TEV) technologies, and microbumps, as well as process technologies for horizontal interconnects like thin film technologies for redistribution both on chips and on encapsulation materials. A technology base is needed for 3D stacking as well as horizontal interconnecting of dies.
- Encapsulation technologies, handling carriers as well as panels which on the one hand protect dies, and on the other hand allow optimum electrical performance. Chip embedding technologies like chip embedding in mould 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 an enabler 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 Section 12.1 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. Research and development in this area need a strong link especially into materials and their compatibility, taking also into account challenges with respect to heat dissipation. In the last 10 years nearly all assembly and packaging materials changed and in the next 10 years it is expected they will change again. Also, a close link to the design chapter is crucial.
- Chip-Package-Board co-design. This will be of utmost importance for introducing innovative products efficiently with short time to market and this work is closely linked to the work described in Chapter 11 of this SRA.
- 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.

System requirements and semiconductor device technology (Challenge 1 and 2) will evolve at the same time, creating a momentum for further interconnect pitch scaling for 3D integration technology platforms. Hence, the timelines of all 4 challenges of this chapter are strongly connected.

Expected achievements

Keep SiP manufacturing in Europe through research and development of proper processes e.g. parallel processing similar to front-end technologies and wafer level processing, as well as with increasing automation and logistics. Special care should be taken to address reliability and quality.

Process technology development for multi-chip embedding and flexible substrates. Process technology for heterogeneous chip integration. Continuous improvement of materials aspects and thermal management, including high temperature package characterization and modelling.

15.3.4. Major Challenge 4 Maintaining world leadership in Semiconductor Equipment, Materials and Manufacturing solutions

The equipment, materials and manufacturing sector in Europe is a standalone sector providing the world market with best in class technologies to enable manufacturing of miniaturized Electronics Components. As this field and sector covers such a wide range of process technologies, this Grand Challenge is divided into 3 sub challenges:

- More Moore (MM): Develop European know-how for advanced Equipment, Materials & Processes for sub-10nm semiconductor devices & systems manufacturing
- More than Moore (MtM) and SiP: Strengthen European competitiveness by developing advanced MtM Equipment, Material and Manufacturing solutions for front-end-of-line (FEOL) and back-end-of-line (BEOL) wafer processing and device (including SiP and SoC) as well as Assembly and Packaging (A&P)
- Manufacturing Technologies: Develop new fab manufacturing and appropriate Equipment & Manufacturing 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.

15.3.4.1. MORE MOORE

This sub 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 developed roadmaps such as the IRDS (International Roadmap for Devices and Systems). will also be taken into consideration.

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

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

- 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 support big data management with predictive methodologies.
- Thin film processes including thin film deposition, such as (PE)ALD and PIII for doping and material modification, and corresponding equipment and materials.
- Equipment and materials for wet processing, wet and dry etching, thermal treatment, laser annealing, and wafer preparation.
- Si-substrates, Silicon on Insulator substrates, SiC, III-V materials, advanced substrates with multifunctional layer stacking (e.g. highly dense 3D), including insulators, high resistivity bulk substrates, mobility boosters, corresponding materials, manufacturing equipment and facilities.

Expected Achievements

Ambition of the European E&M industry for advanced semiconductor technologies is to lead the world in miniaturization 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 wafer processing including the respective infrastructure for sub-10nm technologies.

15.3.4.2. MORE THAN MOORE

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 More than Moore Electronics Components and Systems, such as sensors and sensor systems, MEMS (Micro-Electro-Mechanical Systems), Advanced Imagers, power electronics devices, automotive electronics, embedded memory devices, 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 equipment will be required for future A&P, creating new R&D challenges and business opportunities. Over the last decade, nearly all assembly and packaging materials have been replaced by more advanced materials - a process that is expected to continue. This will have a strong impact on future processes and equipment.

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

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

Expected Achievements

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 More than Moore equipment is typically designed for high-volume continuous production in a More Moore environment, which requires major modifications or re-design. The performance of any future MtM production tools must be enhanced for smaller lot production providing high flexibility and productivity at low Cost-of-Ownership (CoO).

Furthermore, the likewise 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 respective equipment.

15.3.4.3. MANUFACTURING TECHNOLOGIES

The sub 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 fab management solutions

that support flexible and competitive ECS manufacturing in Europe, as well as the world market.

For that, aspects of digitalisation including 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. Next to that, it will be key to adapt work-flows to new, data-driven manufacturing principles adopting Artificial Intelligence, Big Data and deep learning methods.

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 data driven and 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 and virtualized, allowing information to flow between factories in order to facilitate rapid diagnostics and decision making, also through BYOD (Bring Your Own Device) concepts. Enhancing the data security in fab environment is of increasing importance.

The focus of high-mix/low-volume manufacturing will be on flexible line management for high mix, and possibly distributed manufacturing lines as well as on reliability and quality. New manufacturing techniques combining chip and packaging technologies (e.g. chip embedding) will also require new manufacturing logistics and technologies (e.g. panel moulding etc.).

Expected Achievements

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, functionality, defectivity,) will be needed.

Generic solutions are required for current and future fabs that allow high-productivity production of variable size, and energy-efficient, sustainable, resource-saving volume production. The introduction of big data based control system architectures, making use of high performance computing systems, should allow for fab digitalisation, including predictive yield modelling and holistic risk and decision mastering. This requires the integration of control methods and tools and knowledge systems.

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.).

15.4. Strategy

Focused projects in the TRL 2 to 5 are needed as technology push to enable new applications. Technologies will drive the realization of industry roadmaps in MM, MtM and SiP. The required efforts include further CMOS scaling and related equipment development, power electronics, III-V and 2D materials, RF technologies, integrated logic, photonics, 3D integration technologies, MEMS and sensor systems, interlinked with key application challenges. Similarly, to enable the development and production of future generations of SiP hardware in Europe world-leading research is needed to prepare the proper system integration technologies, Further, attention will be given to emerging technologies and materials, and to new developments in the equipment and materials industry, in which Europe has a leading position.

Extended projects will aim at pilot lines with emphasis on TRL 4 to 8 to deliver industry-compatible flexible and differentiating platforms for strategic demonstrations and in order to sustain manufacturing competence, and to pilot lines for SiP hardware demonstration. Research and development on processing (front-end technologies, wafer level processing, assembly and packaging as well as and automation and logistic), is a prerequisite to setup and to keep SiP manufacturing infrastructure in Europe.

Other TRL 4-8 project need to target testbeds and demonstration for emerging applications domains like IoT infrastructure, Industry 4.0, sustainable mobility, incorporating the advanced technologies, also under the umbrella of flagship projects.

More advanced R&D activities, at level 2-5 can be included also in pilot lines and testbed projects at higher TRLs, to provide the fundaments to enable EU companies to set up their dedicated technology capability, and to prepare for next generation products in a sustainable way. This ensures Europe’s competitive position and will keep high quality jobs in Europe.

A specific requirement of European semiconductor manufacturing industry is the ability to cope with high volumes and high quality while enabling flexible line management for high mix, and distributed manufacturing lines. Therefore, manufacturing science projects and demonstrations at high TRLs are needed for the validation of new technologies and equipment, and for mastering cost competitive semiconductor manufacturing in Europe,

including packaging and assembly, while achieving sustainability targets (resource-efficiency and “green” manufacturing). It will require a productivity aware design (PAD) approach with focus on predictive maintenance, virtual metrology, factory simulation and scheduling, wafer handling automation and digitalisation of the value chain for artificial intelligence based decision management. In addition, attention should be given to big data based control system architecture: viz. predictive yield modelling, and holistic risk and decision mastering (integrate control methods and tools and knowledge systems).

Attention should 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).

15.5. Timeframes

All leading European industry and research actors align their activities with international roadmaps and timelines. Roadmap exercises are being conducted in various projects and communities like NEREID and the recently announced IEEE IRDS in which European academia, RTO’s and industry participate. For system integration also the iNEMI and the new Heterogeneous Integration Roadmap activities are considered The European R&D priorities are to be planned in synchronization with the global timeframes and developments, which are under continuous adaptation. The timelines below are high-level derivatives from these global evolutions and follow the structure of the four grand challenges described above:

1. Developing advanced, logic and memory technology for nanoscale integration and application-driven performance;
2. More than Moore and Heterogeneous System-on-Chip (SoC) Integration;
3. Heterogeneous System-in-Package (SiP) integration;
4. Maintaining world leadership in Semiconductor Equipment, Materials and Manufacturing solutions.

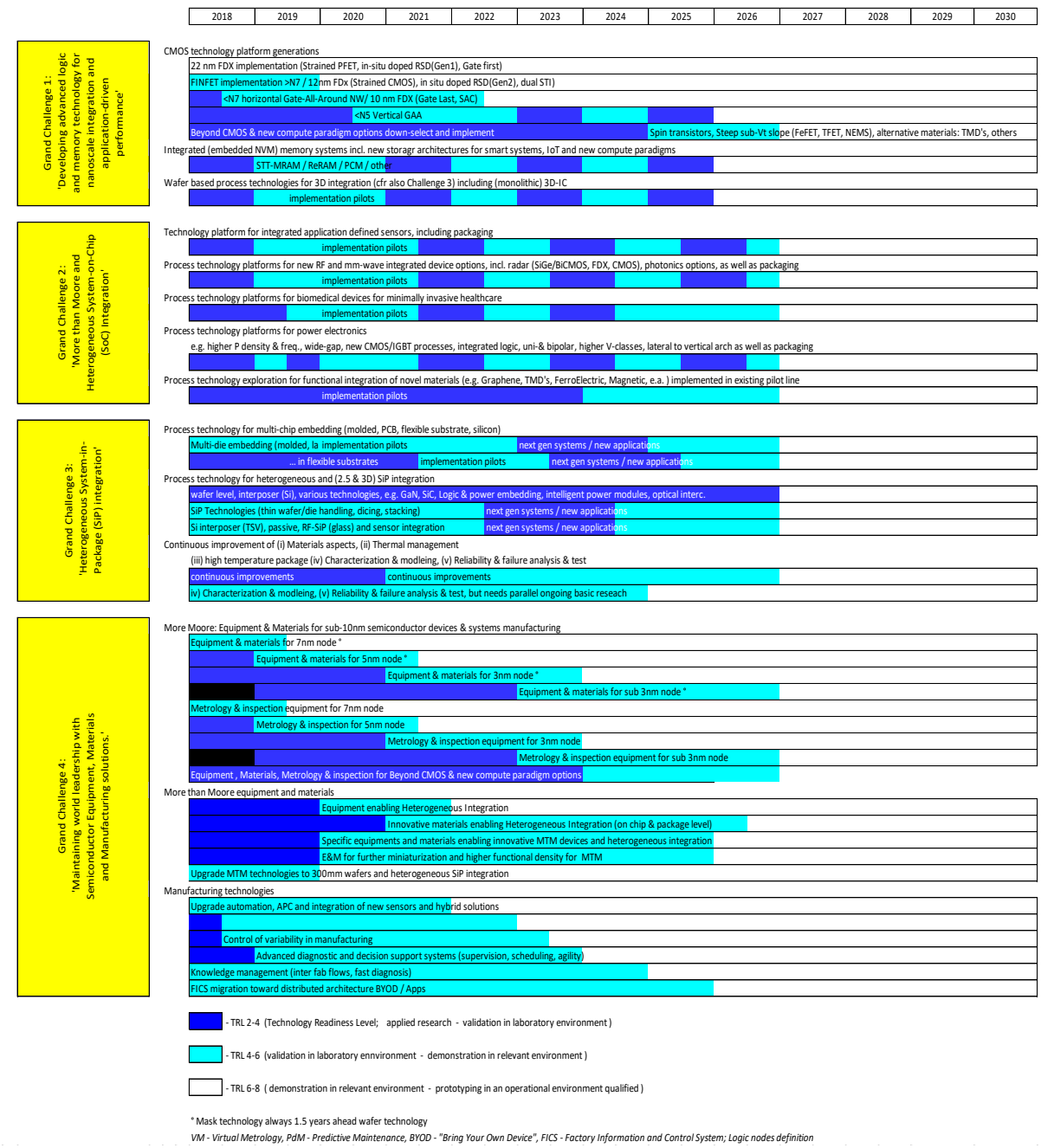


Figure 43 - Roadmap timeline for Process Technology, Equipment Materials and Manufacturing

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. Dedicated process technologies (e.g. low power and high operating temperature) will follow feature scaling with some delay, focusing on other performance indicators. Areas where the roadmaps are less clear (e.g. new computing paradigms) are introduced at low TRL levels although timelines are not very clear. Digitalisation of the European ECS value chains lacks well behind Asia and US. It needs attention and effort now to gain competitive advantages.

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. The timing of new Equipment & Manufacturing solutions for these challenges should be derived from the schedules of the major European semiconductor manufacturers. This includes 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 technologies of tomorrow.

Firstly, the development of sub-10nm solutions in terms of equipment and materials as part of Grand Challenge 4 need to be 2-3 years ahead of mass adoption and are of critical importance to maintain the European leadership. Secondly, new Equipment and & Materials solutions should be developed in line with the needs defined in the roadmaps of challenge 1 up to 3. Lastly, 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), whereas 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.

15.6. Cross references & synergies

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. 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.

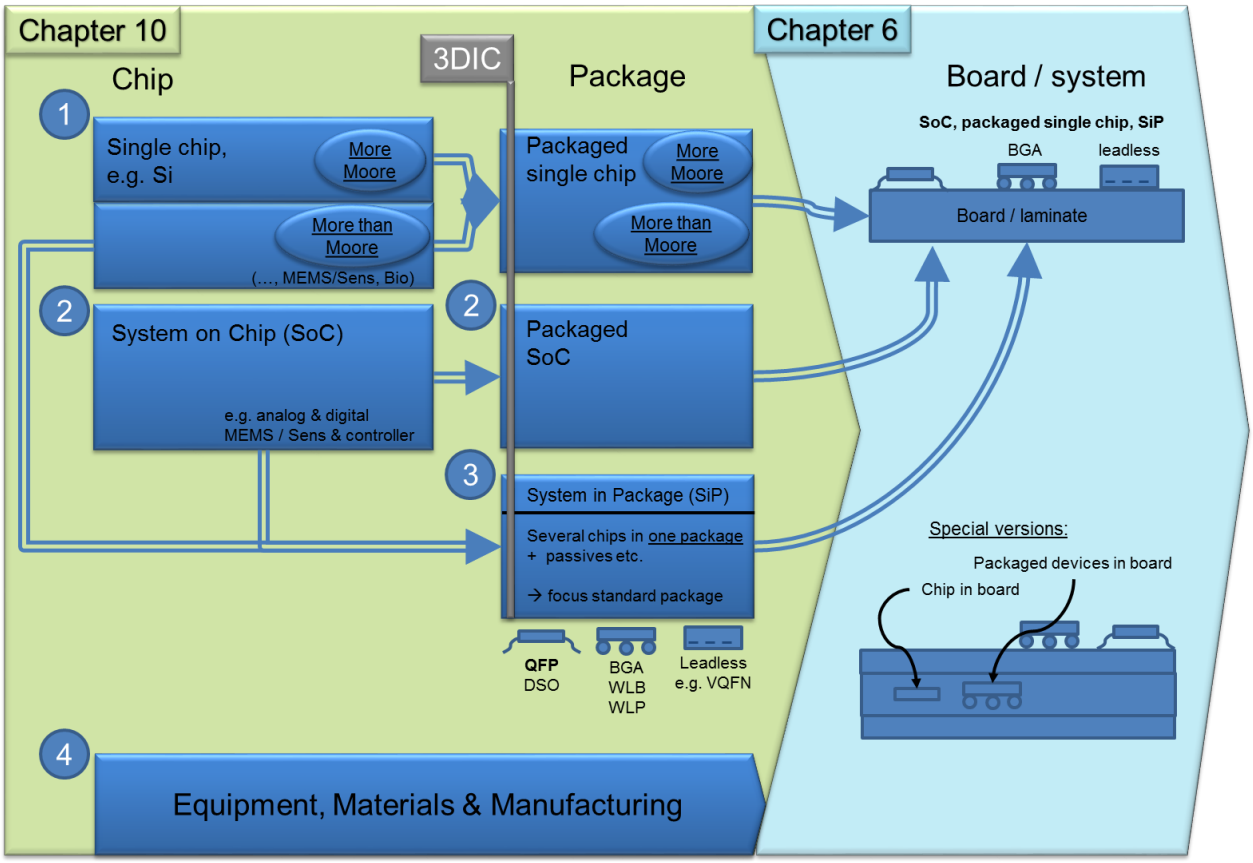


Figure 44 - Close connection between electronics component development in this chapter with next level heterogeneous system integration in chapter 16

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, computing 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, it is needed to consider the integration of the whole system. Therefore, the scope should not be restricted to semiconductor devices only; instead, research must be combined 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 a 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 modeling 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.

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.

16. Appendix to Chapter 6

16.1. Competitive situation of automotive industry in Europe

More specifically, the European Union is home to 15 international car manufacturers producing around 20 million vehicles per year. It is also home to world-leading automotive electronics semiconductor, embedded software and system suppliers.

Automotive semiconductor revenues in Europe reached €4.0 billion in 2012, representing more than 30% of the world market. According to Strategy Analytics1, automotive semiconductor revenues are expected to grow 7% (CAGR) over the five-year forecast period.

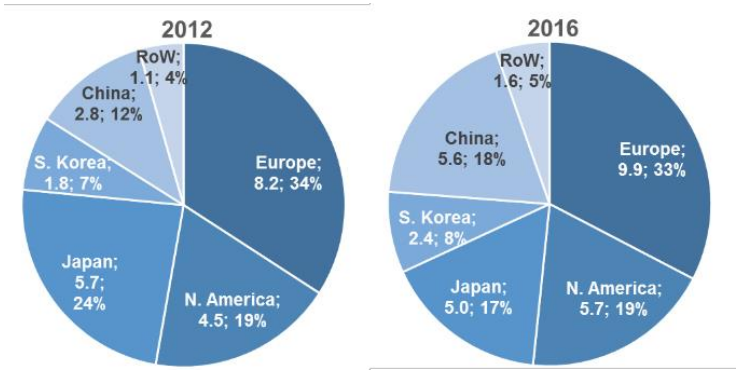


Figure 45 - Automotive Revenues by Regions (USD billions) Source: (Analytics, 2013)

The revenues in Europe are split over the following market segments:

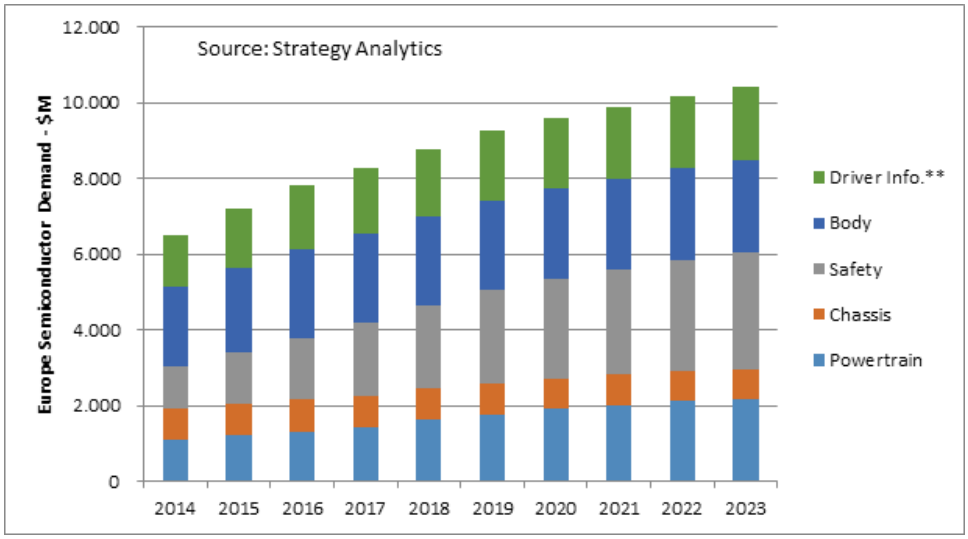


Figure 46 - Automotive Revenues by Market Segments (USD millions). Source: Strategy Analytics

Of all the cars sold, more and more of these cars will be connected in the future. According to CISCO, 25% of all cars will be connected in 2023.

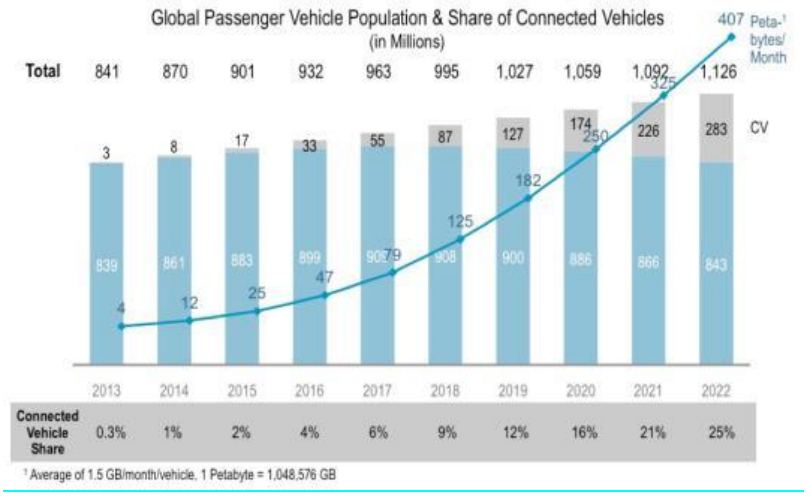


Figure 47 - Global Passenger Vehicle Population (Source: CISCO 2011)

16.2. Details to high priority R&D&I topics for Grand Challenge 2 in Application Chapter Transport & Smart Mobility

Environment recognition

- New trusted integrated sensors also for harsh conditions (cameras, radar, lidar, ultrasonic, ...), including their SW for real-time data acquisition management
- Sensor fusion, video data analysis and annotation
- Methods to evaluate, reproduce, overcome and validate fault (and/or degraded) behaviour for exceptional situations in environment perception
- Lifetime, reliability, robustness
- Quality attributes of sensors; aging of sensors; influence of environment to sensor quality; handling of quality attributes of sensors in software; electromagnetic compatibility
- Redundancy concepts
- Traffic scene interpretation (also for different countries); scenario categorization; catalogue of safety relevant scenarios; scenario description language, system context modelling; tools and methods required for scene interpretation
- Scene and object recognition
- Driver health/emotion/intention recognition
- Support and harmonization of object lists, identifications, attributes, sensor protocols; open platforms for scenarios

Localization, maps, and positioning

- Crowd-sourced or shared data acquisition of mapping data

- Situation-aware turn-by-turn navigation
- Reliable, accurate and high-precision localization, GNSS Galileo & GPS, lane-level resolution positioning
- Combination and fusion of different available data sources (stationary/infrastructure-based, dynamic data, cloud data…)

Control strategies

- Transport system level: optimization of throughput and safety of all traffic in a larger area (e.g. city, motorway section...). Provides system data and recommendations to the lower levels such as speed limits, personalized re-routing
- Cluster-of-vehicles level: strategies to optimize the flow and safety of a group of closely-spaced, temporarily connected vehicles, perhaps travelling together (possibly forming a platoon) or approaching an intersection
- Individual-vehicle level: control strategy for optimization of safety and speed of individual vehicle, based on available data at each of the level. This is the ultimate decision and responsibility level.
- Framework for scene interpretation, environment object handling to separate sensing from control strategies
- Mission-oriented automated system SW: Mapping and routing, online mission verification, emergency control SW, fail operational strategies
- Technical goal-oriented collaborative automated system: Mapping and routing, control strategies & real time data processing; ADAS functions, ADV functions
- Fault-tolerant control strategies & real-time data processing
- Distributed control (network of control units, multi-core, multi-processor, cloud-based)
- Human-vehicle interaction (e.g. handover scenarios, VRUs interaction)

HW and SW platforms for control units for automated mobility and transportation (including also support for artificial intelligence)

- Artificial intelligence (AI) - intelligence versus deterministic response
- New methods, tools, HW and SW for development of AI -based systems
- Efficient and safe use of resources in multi-core/many-core processor architectures
- Test procedures for AI enabled components, standardization of test procedures
- Bring AI towards industrialization
- Disruptive applications for AI in mobility and transportation

Communication inside and outside vehicle

- Dynamically reconfigurable networks (“Drive-by connectivity”)
- Networks that support real-time, mixed criticality, availability, dependability

- Big-data handling and data-governance inside vehicles and between vehicles and the environment
- Seamless integration and cooperation of multiple communication platforms (amongst others: V2X, Radar, DAB / digital audio broadcasting, 5G, eLicense Plates, NFC, Bluetooth, 802.11p, etc.)
- Safe and secure communication (e.g. build-in data security and privacy)
- Intelligent in-vehicle networking (wire-based and wireless)
- Secured high-speed in-vehicle networks
- Multi-layered privacy protecting and secure elements in architectures and components
- Standards and interoperability

Testing and dependability

- Test methods for connected, cooperative, automated mixed-criticality systems
- Methods and tools to support virtual approval (shift towards virtual homologation)
- Functional safety along life cycle
- Model-centric development and virtualization of testing by digitalisation
- Sensor, actuator, communication test infrastructure and tools (including deep learning sensor algorithms)
- Test methods for AI-based systems
- System validation and non-regression testing from real-world data
- Large scale field tests of secure highly automated vehicles, field operational tests (FOT), naturalistic driving studies (NDS)
- Software tools for automatic validation
- Contemporaneous logging and secure, reliable and privacy protected data retention for incident reconstruction
- Continuous cross-industry learning processes for the development of highly automated transport systems are established enabling fast take up of new features and capabilities mandated from analyzing fleet data with the objective to continuously enhance system safety and performance.
- Alignment of test procedures/scenarios/methods of test-fields/labs for connected, automated operation
- Cost effective usage of test infrastructure validation of fail-operational concept for unknown environments
- Training methods for automated driving functions (e.g. compare open loop ADV functions with manual driver reactions)

Swarm data collection and continuous updating

- Check field operational data and derive scenarios of it, approval of scenarios for further validation usage

- Learning process for automated vehicles (including necessary online SW update-infrastructure), SW improvement cycle using field data / big data analysis
- Safe and secure over-the-air SW update
- Reliable and temper-free black box recorder for near incident data (including dependable communication and near incident scenario evaluation, definition of minimal data set)

Predictive health monitoring for connected and automated mobility

- Self-aware systems guaranteeing that the risk produced by highly automated transport systems is reduced to an acceptable minimum.
- On-board diagnostics for automated transport systems
- Methods for self-assessment / self-diagnosis of health state, degradation, system state, system condition across all ECS levels
- Methods and tools (development of ECS but also in-vehicle usage) to cope worst case scenarios

Functional safety and fail-operational architecture and functions (sensors, electronics, embedded software and system integration)

- A common evolvable fault tolerant system architecture, including onboard and infrastructure, is standardized to enable the necessary innovation speed and allow affordable validation efforts.
- Strategies for HW and SW redundancy
- Fail-silent and fail-safe systems
- Development frameworks to design fail-operational ECS
- Service-oriented distributed dynamically reconfigurable HW/SW architecture
- Strategies for safe operation / safe stop / safe actuation in emergency situations
- New generation technologies for automated driving based on competitive consumer electronics

17. Appendix to Chapter 11

This appendix gives a detailed list of topics in each R&D&I Area of every Challenge of Chapter 11: Systems and Components: Architecture, Design and Integration.

17.1. Major Challenge 1: Managing critical, autonomous, cooperating, evolvable systems

Topics of Major Challenge 1 are collected in three categories (high priority R&D&I areas):

Models, model libraries, and model based design technologies

- Re-usable, validated and standardized models and libraries for
  - systems contexts (use cases, scenarios)
  - environment (including different environment factors and conditions)
  - humans behaviour (as operators, users, cooperation partners)
  - for systems behaviour, including
    - environment/situation perception (incl. sensor models)
    - situation interpretation and prediction
    - self-awareness, -management and healing (incl. reconfiguration)
    - handling of uncertainty, inaccuracy and faults
- Advanced modelling techniques for future ECS
  - combining rigorous (functional, physical and data based) behavioural and property modelling and measurement/observation based modelling
  - supporting V&V of heterogeneous Systems,
  - supporting alteration management and model transformation
  - for learning and adaptive systems
- Model based design methods and interoperable tool chains for critical systems, supporting constraint driven requirements (including Standards like ISO26262, EAL6+), and (incremental) certification and homologation
- Extended specification capabilities (including requirement engineering, mission profiles, use cases, architectural design, transition of informal to formal specification ...) to enable executable and consistent specifications of all design aspects and in all stages of development

Verification and Validation (V&V) and Test for critical systems: Methods and Tools

- Model based verification, validation and test methodology and interoperable tool chains and platforms for critical systems,
  - supporting heterogeneous systems
  - starting from high levels and spanning across different level of abstraction
  - including coverage, error mode analysis, generation of HW/SW V&V from models and connection of model-based design and verification
- Automated derivation of verification procedures and tools from requirements and models, back annotation of verification results, interface between requirement engineering and V&V environment
- V&V and test methods including tool support
  - for Life-Cycle and in-service phase, including support for

        - monitoring systems health state and exception conditions
        - reconfiguration, adaptation, handling of faults and aging
        - upgrades in the field and evolvability
        - maintainability
        - special situations (start-up, power-down,…)
    - for adaptive, cognitive and learning systems, including V&V for strategy synthesis
    - for Human-Machine Interaction, collaborative decision making, cooperation strategies and activities, etc., including human (health) state and intention prediction
    - for autonomous systems including (a) environment/situation perception (incl. sensor models), (b) situation interpretation and prediction, and (c) handling of uncertainty, inaccuracy and faults
- Methods for the hierarchical verification of the whole system (incl. re-use of already verified components, scene and environmental analysis, connection of formal and simulative methods, incremental verification)
- Concepts and procedures for the evaluation of functional safety, robustness and reliability (hierarchical management of requirements, criteria and system characteristics / functions, determination of errors and failure probabilities, ...)

(Virtual) Engineering of Electronic Component and Systems (ECS)

- Collaboration concepts and methods, platforms and interoperable tools for interdisciplinary, holistic virtual engineering of ECS covering the whole value chain, spanning organisations, engineering domains, and development activities
- Methods and interoperable tools for virtual prototyping of complex, networked systems with a large number of components (e.g., IOT systems)
- Engineering support (libraries, platforms, interoperable tools)
    - for evolvable and adaptable systems including adaptation to human needs and capabilities, to changing and unknown environments/situations/contexts, enabling upgradability while ensuring functional, structural, and sematic integrity during run-time, all embedded within a holistic life-cycle management
    - for the design and operation of Open-World Systems (distributed control-loops, cognitive systems, handling of unreliable information, safe fall back strategies, legacy systems/components, monitoring, self-awareness and self-healing, fault tolerance layers, etc.)
    - for the design and operation of cognitive, cooperating systems (sufficient observability of the environment, handling of unknowns, on-line synthesis of (cooperation) strategies, reasoning engines, value governance, learning…)

17.2. Major Challenge 2: Managing Complexity

Topics of Major Challenge 2 are grouped in four categories (high priority R&D&I areas):

Systems Architecture

- Extended methods for architectural design: Support for
    - systems with thousands of components
    - metrics for functional and non-functional properties

- early architectural exploration, considering use cases and application context, enabling evaluation of design alternatives (e.g. centralised vs. decentralised...) and consistency checking

- Design methods and architectural principles, platforms and libraries supporting
  - V&V, Test, and Life-Cycle-Management of complex, networked ECS: Modular Architectures and platforms supporting compositional and incremental V&V and Test, Adaptability, Upgradability, Evolvability, Maintainability)
  - Self-management, Self-Awareness and Self-Healing (including monitoring and diagnosis on hardware and software level in real-time, self-assessment, support for re-configuration, redundancy, down to integrated DFT/BIST tests)
  - cognitive and adaptive systems (support for cognitive computing, adaptive algorithms, artificial intelligence, machine learning, neuromorphic architectures…)
- Model based system architecture, including models representing requirements and specifications in dynamic and executable architectures, to ensure among others preservation of consistency of architectures throughout the design process and life-cycle

System Design

- Hierarchical Concepts and Standards for IP Modelling (component based design, re-usable components on all levels, extended analysis techniques, coverage and error mode analysis, architecture and system models for Soft-IP)
- Methods and Tools for Model Driven Engineering, supporting model creation and transformation (incl model extraction and model learning), model languages (incl. Domain Specific Languages), model management, and scalability of model based approaches
- Methods and Tools for component based HW/SW Co-Design for complete products incl. heterogeneous systems, embedded cores, software blocks, digital and analogue IP, subsystems, (possibly unknown) system environment and (fast) changing application context
- Methods and Tools for efficient virtual prototyping (fast simulation/emulation of embedded platforms, early software integration and validation, adaptive, re-configurable real-time platforms, co-simulation of heterogeneous modelling paradigms, cloud-support, cognitive computing)
- Design and Analysis methods for multi-/many-core systems, including support for complex software stacks and DSLs, and for migration of legacy software)

Methods and tools to increase design efficiency

- Seamless and consistent design and tool chain for automated transfer of abstract (system level) descriptions into functional HW/SW blocks (High-Level synthesis, Generator-based design, Co-Simulation of heterogeneous models) with inclusion of design checking and consideration of simultaneous technology and product development.
- Strong support of package, board and sensor/MEMS (co-) design including die-embedding and 2.5/3D integration (design exploration, mixed discipline modeling, multi-criteria evaluation of functional and non-functional properties, optimization, and integrated DFT development
- New methods and tools to support new design paradigms: multi / many core architectures, increased software content, no cs, GALS, neural architectures, design knowledge acquisition, artificial intelligence, big data methods, machine learning, etc.

- Support of new technologies: FD-SOI, graphene, nanotubes,…, <7nm technology
- New approaches to handle analog/mixed signal design (capturing and formalizing designer knowledge, guided design, automatic generation of blocks, synthesis of analog blocks)

Complexity reduction for V&V and Test

- V&V methods to prove safeness and soundness of real-time complexity reduction in situation representation and situation prediction
- Hierarchical system verification using already verified components and verification process re-use
- Methods and tools to support scenario based V&V and Test, including scenario analysis, scenario selection, combination of formal proof, simulation and test techniques,
- Virtual platform in the loop: Enabling the efficient combination of model-based design and virtual platform based verification and simulation
- Methods and tools for V&V automation and optimization including test optimization and test system generation, including handling of product variability

17.3. Major Challenge 3: Managing Diversity

Main R&D&I activities this challenge 3 are grouped in four categories (high priority R&D&I areas):

Multi-objective optimisation of components and systems

- Integrated development processes for application-spanning product engineering along the value chain (modelling at different abstraction levels, management of constraints in different domains, multi-criteria, cross-domain optimization, standardized interfaces)
- Consistent and complete Co-Design and integrated simulation of IC, package and board in the application context (integration of communication systems, mechatronics components and their interfaces)
- Modular design of 2.5 and 3D integrated systems (re-use, 3D IPs, COTS and supply chain integration, multi-criteria design space exploration for performance, cost, power, reliability, etc...)

Modelling and simulation of heterogeneous systems

- Hierarchical Approaches for Modelling on System Levels (consistent models at different abstraction levels, model simplification and order reduction, model transformation and adaptive models with automatic adjustment of abstraction level, accuracy and complexity)
- Modelling methods to take account of operating conditions, statistical scattering and system changes(application-specific loads, variations in production, commissioning and operation, degradation and aging effects)
- Methods and tools for the modelling and integration of heterogeneous subsystems (analog, digital, RF, antennas, power, memory, buses, optics, passive components)
- Methods for hardware software co-simulation of heterogeneous systems at different abstraction levels (co-simulation of software and sensors and different modelling paradigms,

hardware-in-the-loop simulation, heterogeneous simulation (from FEM to inaccurately described systems in one environment)
- Modelling methods and model libraries for learning, adaptive systems
- Models and model libraries for chemical and biological systems

Integration of analog and digital design methods

- Metrics for testability and diagnostic efficiency (including verification, validation and test), especially for AMS designs.
- Harmonization of methodological approaches and tooling environments for analog, RF and digital design (reuse of analogue IP on system level, synthesis and verification for analogue and RF components and heterogeneous systems considering the package)
- Automation of analog and RF design (high-level description, synthesis acceleration and physical design, modularization, use of standardized components)

Connecting digital and physical world

- Advanced simulation methods (environmental modelling, multi-modal simulation, simulation of (digital) functional and physical effects, multi-level/multi-rate simulation, emulation and coupling with real hardware, connection of virtual and physical world)
- Novel More than Moore design methods and tools (design exploration, automated variant generation and evaluation, synthesis approaches for sensor components and package structures)

17.4. Major Challenge 4: Managing Multiple Constraints

R&D&I activities in this challenge are grouped in three categories (high priority R&D&I areas)

Ultra-Low Power Design methods

- Advanced methods for ultra-low-power design (efficiency modelling, low-power optimization taking into account performance parameters)
- Design methods for (autonomous) ultra-low-power systems, taking into account application-specific requirements (function and performance, safety and security, communication, energy demand profiles / energy recovery, system life, boundary conditions for energy harvesting and storage)
- Method for comprehensive assessment and optimization of power management and power consumption (normal operation, switching on and off, behaviour in the event of a fault) including the inclusion of parasitic effects (substrate couplings, etc.)

Efficient modelling, test and analysis for reliable, complex systems considering physical effects and constraints

- Hierarchical modelling and early assessment of critical physical effects and properties (ESD, substrate coupling, latch-up, EMC, thermal-electrical interactions, thermo-mechanical stress, power and signal integrity) from SoC up to system level
- Design and development of error-robust circuits and systems (methods for monitoring and fault detection, adaptation strategies, intelligent redundancy concepts, adaptive algorithms)
- Production-related design techniques (modelling, characterization, variability and reliability analysis, yield optimization, lithography friendliness, measurement and prognosis of yield losses)
- Consistent methods and new approaches for (multi-level) modelling, analysis, verification and formalization of ECS's operational reliability and service life (comprehensive consideration of operating conditions and dependencies between hardware and software, detection and evaluation of complex fault failure probabilities and dependencies)
- Consistent design system able to model and optimize variability, operational reliability (including degradation/aging), yield and system reliability (including the consequences for the qualification), considering dependencies
- Analysis techniques for new circuit concepts and special operating conditions (Voltage Domain Check, especially for Start-Up, Floating Node Analysis ...)
- Advanced test methods (test generation for analogue and RF design, baseband testing with massive BIST usage, hierarchical production test (including diagnostics, online test troubleshooting or error correction), intelligent concepts for test termination, automated metrics/tools for testability and Diagnosis, extraction of diagnostic information)
- Methods and tools for monitoring, diagnostics and error prediction for ECS (online and real-time monitoring and diagnostics, intelligent self-monitoring of safety-critical components, life expectancy)

Safe systems with structural variability

- Architectures, components and methods for adaptive, expanding systems (self-)monitoring, diagnostics, update mechanisms, strategies for maintaining functional and data security, life cycle management, adaptive safety and certification concepts)
- Design methods and tools for adaptive, expanding systems (realization of real-time requirements, high availability and functional and IT security, evaluation of non-functional properties, analysis of safety and resilience under variable operating conditions)
- Novel simulation approaches for the rapid evaluation of function, safety and reliability (real-time simulation and simulation of mixed virtual real systems, approximate computing, approaches for mixed criticality)
- Security concepts for highly connected and adaptive, expanding systems (self-monitoring, environmental analysis, aging-resistant chip identification techniques, ensuring functional safety through robustness guarantees).

17.5. Major Challenge 5: Integrating miniaturized features of various technologies and materials into smart components

Main R&D&I activities in the three identified categories (high priority R&D&I areas of Major Challenge 5 are:

Activity field 1: Functional Features

- Selective gas (CO, CO_2, NO_x, VOC, etc.) sensing components
- Low power wireless architectures
- PMICs with high efficiency at very low power levels and over a wide range of input voltages (AC & DC)
- Selective detection of allergens, residues in food/water, atmospheric particles, etc.
- Disease monitoring & diagnostics (at home, POC, animal health)
- Bio-sensors and bio-actuators
- MOEMS and micro-optics
- Various sensors and systems in package for autonomous cars, industrial robots, smart energy applications, etc.
- Component-level features for self-diagnosis (PHM detectors)
- Harvesters and storage devices (e.g. microbatteries, supercapacitors), including 2D, 3D and solid-state for feeding low or zero power devices
- Hardware solutions for security and privacy

Activity field 2: Materials

- Surface coatings for multi-functionality on the same base structures
- High efficiency photonic materials
- New / alternative organic and bio-compatible materials
- New materials and features for sensing (CNT, Graphene, Nitrogen voids, etc.)
- Low quiescent/leakage power material/devices for sensors
- Materials for low power, fast responding gas sensors and occupancy sensors
- Non-toxic, scalable, high density features materials for energy harvesting sources (thermoelectrics, piezolectrics, triboelectricity…) and more performing electrodes and electrolytes for improved capacity and conductivity of energy storage devices
- Rare earths replacement, e.g. for magnetics
- Heterogeneous integration of new materials, sensors, actuators for miniaturised chips (also for high temperature and photonics)

Activity field 3: Integration Technologies and Manufacturing

- 2D and 3D printing technologies for heterogeneous system integration and rapid manufacturing
- Robust integration of multi-component systems (sensors, actuators, electronics, communication, energy supply (including e.g. fluidics and photonics)
- Key technology areas (printing, etching, coating, etc.)
- Manufacturing & health monitoring tools (including tests, inspection and self-diagnosis) for components
- Quantum sensors and associated integration

17.6. Major Challenge 6: Providing effective module integration for highly demanding environments

Main R&D&I activities in the three identified categories (high priority R&D&I areas) of Major Challenge 6 are:

Activity field 1: Functional Features

- Board-level signal processing and control features for self-diagnosis and self-learning
- Smart power (mini-) modules for low-power sensing/actuation and efficient power transfer
- Low-power sensor nodes for real-time data processing
- High performance signal quality under harsh environmental conditions
- Protective housing and coating features (e.g. against chemicals)
- Photonics features like optical sources, paths and connectors integrated into PCB
- Advanced and active cooling systems, thermal management
- EMI optimized boards
- 3D board & module design
- Board level high speed communication features

Activity field 2: Materials

- Heterogeneous integration of new materials for miniaturised sensor & actuator modules
- Recycling and repair of modules
- Transducer materials (e.g. CMOS compatible piezo, e.g. flexible solar panels) that can be integrated into SiPs
- Materials for flexible devices
- Materials for coatings, potting, and overmolding
- New thermal interface materials
- New substrate materials on board level

Activity field 3: Integration Technologies and Manufacturing

- Transfer printing of heterogeneous components on various substrates
- Heterogeneous 3D integration of sensors, actuators, electronics, communication, and energy supply features for miniaturised modules
- Highly miniaturised engineering and computer technologies with biochemical processes
- Bio-mimicking (bio-hybrids, fluidics)
- Manufacturing & health monitoring tools (including tests, inspection and self-diagnosis) for components
- Direct manufacturing and rapid prototyping
- Automation and customization ('towards I4.0') in module manufacturing
- Flexible and stretchable devices and substrates
- Chips, passives and packaged components embedded in board
- 3D printing of IC components on top of PCBs

17.7. Major Challenge 7: Increasing compactness and capabilities by functional and physical systems integration

Main R&D&I activities in the three identified categories (high priority R&D&I areas) of Major Challenge 7 are:

Activity field 1: Functional Features

- Effective and reliable energy generation, harvesting and transfer
- Efficient computing architectures for real-time data processing in sensor nodes
- In-situ monitoring in automation, process industry and medical application

- Biomedical remote sensing
- System integration of wide bandgap semiconductors
- System health management based on PoF models (and not statistical)
- Perception techniques
- Sensor fusion and cyberphysical systems
- Data and system safety, security and privacy
- Low power RF architectures for asset tracking and low data rate communication (e.g. UWB, LoRA)
- Modularity and compatibility across development generations (interface definition, standardization)
- Thermal management on system level

Activity field 2: Materials

- ICT for diverse (material) resources monitoring and prognosis
- Recycling and repair of systems
- New materials and concepts for humidity transport into and out of the (sensing) systems
- New materials for improved thermal management

Activity field 3: Integration Technologies and Manufacturing

- Volume reduction (per lot due to customization) in system manufacturing
- Improved signal integrity (EMC)

18. Appendix to Chapter 14.4.4

More details on foreign export restrictions:

One of the most well-known export restriction is known as ITAR:

The ITAR term is often used as a shortcut for 'US Export Control Laws', which restrict exports of designated goods and technology. These federal laws are implemented by the US Department of Commerce through its Export Administration Regulations (EAR—trade protection), by the US Department of State through its International Traffic in Arms Regulations (ITAR—national security), and by the US Department of Treasury through its Office of Foreign Assets Control (OFAC—trade embargoes). The ITAR is concerned with items that are designed or modified for military use. The EAR regulates items designed for commercial purposes that can have military applications such as computers, pathogens, etc.

Any product that includes or is bundled with US-origin items is subjected to US Export Control Laws, irrespective of the licensing conditions of these items. US-origin is assumed for any item (commodity, technology, or software) contributed from a US national anywhere in the world, or from a foreign national on the US territory. Items physically or virtually located in the US including artifacts in data centers are also considered as US-origin. Because of the extra-territorial application of US Export Control Laws, these become a re-export control of products from one country to another. If an item is a US-origin and subject to the US Export Control Laws, it remains so regardless of how many times it is reexported, transferred, or sold. In particular, an export license is required for any reexport or in-country transfers of US-origin items or non-US-made items subject to the EAR, unless exemptions below apply.

The main exemption to the requirements to obtain an export license according to the US Export Control Laws is for items in the 'public domain'. Public domain items do not have an identified copyright owner. Fundamental research performed by academic institutions is also assimilated to 'public domain', but only as far as no access restrictions existed on the grant agreements that funded this research. Access restrictions that remove the 'public domain' exemption of fundamental research include controls of publication contents, or specific treatment of non-US nationals in the contribution to or diffusion of research results. See for instance https://www.umass.edu/research/sites/default/files/documents/export_controls_and_universities_information_and_case_studies.pdf

The second exemption to the requirements to obtain an export license only applies to EAR, when the value of US-origin items in a product is below a percentage based on 'de minimis' guidelines. The 'de minimis' guidelines set the percentage threshold based on: (1) Export Control Classification Number (ECCN); (2) the ultimate destination of the item; (3) the end-user and end-use for the item. However, the 'de minimis' exemption does not apply in 'except' cases, such as: specific countries of destination (except #1); certain components of high performance computers, and encryption commodities and software (except #2). Further details are available from https://www.bis.doc.gov/index.php/licensing/reexports-and-offshore-transactions/de-minimis-guidelines/18-licensing and https://www.bis.doc.gov/index.php/documents/pdfs/1382-de-minimis-guidance/file

19. Further reading

19.1. Further reading for chapter 9

- 5G white papers, info graphics
  - https://networks.nokia.com/innovation/5g
  - https://apps.networks.nokia.com/5g/index.html
- AI will change field service: http://www.7wdata.be/enterprise-software/4-ways-ai-will-transform-the-field-service-industry/

19.2. Further reading for chapter 10

Several relevant documents are mentioned that provide suggestions for further elaboration:

- AIOTI strategy document, online at https://aioti.eu/
- IERC: the European Research Cluster on the Internet of Things "Internet of Things beyond the Hype", online at: http://www.internet-of-things-research.eu/
- The future of cities; Scenarios that show how people may experience cities in 2035, Philips Lighting. Online at http://www.lighting.philips.com/main/systems/connected-lighting/connected-lighting-for-smart-cities/city-scenarios
- Wearable technology and the IoT, Ericsson, online at: https://www.ericsson.com/en/networked-society/trends-and-insights/consumerlab/consumer-insights/reports/wearable-technology-and-the-internet-of-things#thedemographicdivide
- Edelman-Digital-Trends-Report 2017, online at: https://edelmandigital.com/wp-content/uploads/2016/12/2017-Edelman-Digital-Trends-Report.pdf
- State of the Media Industry 2017, Ooyala, online at: http://go.ooyala.com/rs/447-EQK-225/images/Ooyala-State-of-the-Media-Industry-2017.pdf

20. References

20.1. References for chapter 6

[1] E. Commission, “STRIA Roadmap 3 - Smart mobility and Transport Services and Systems,” Horizon 2020 Commission expert group to assist the Strategic Research and Innovation Agenda (STRIA) initiative (E03420) , Brussels, 2017.

[2] E. C. G. 2. H. L. Group, “GEAR 2030 roadmap on highly automated vehicles,” European Commission, Antony Lagrange - DG GROW, Unit C4, Brussels, 2016.

[3] ERTRAC, “New Automated Driving Roadmap,” ERTRAC, Brussels, 2017.

[4] Mobility4EU, “ACTION PLAN FOR THE FUTURE OF MOBILITY IN EUROPE,” Consortium Mobility4EU, 2017. [Online]. Available: http://www.mobility4eu.eu/wp-content/uploads/2016/10/context-map-deliverable_colours_vectors.pdf. [Accessed 14 08 2017].

[5] Deloitte, “The future of mobility: What’s next,” 2016. [Online]. Available: http://publications.deloitte.nl/mobility#!/the-future-of-mobility-duplicate.

[6] U. Nations, “Paris Agreement C.N.92.2016.TREATIES-XXVII.7.d of 17 March 2016,” United Nations, New York, 2015.

[7] Z. online, “Autoindustrie: Großbritannien will offenbar Diesel und Benziner verbieten,” *ZEIT Online,* no. 26. Juli 2017, 5:09 Uhr Quelle: ZEIT ONLINE, Reuters, mib , 2017.

[8] E. I. Association, “EPOSS Strategic Resource Agenda,” EPoSS, Berlin, 2017.

[9] ERTRAC, “Integrated Urban Mobility Roadmap,” ERTRAC, ARRAC, ALICE, Brussels, 2017.

[10] C. S. JTI, “Work Plan 2014-15,” Clean Sky JTI, Brussels, 2014.

[11] S. Analytics, “Automotive Semiconductor Demand Forecast 2011-2020,” Strategy Analytics, Boston, 2013.

[12] S. W. Group, “Highly Automated Systems: Test, Safety, and Development Processes, Recommendations on Actions and Research Challenges, Management Summary (Editors: Peter Heidl (Bosch), Werner Damm (OFFIS),” SafeTRANS, Oldenburg, 2016.

[13] E. I. A. -. W. G. SRA, “Strategic Research Agenda,” EPoSS Industry Association, Berlin, 2017.

[14] E. I. Association, “European Roadmap on Automated Driving,” EPoSS Industry Association, Berlin, 2014.

[15] S. B. (. Gereon Meyer, Road Vehicle Automation (Volumes 1 to 4), Cham, Heidelberg, New York: Springer, 2014 - 2017.

[16] M. H. (. Daniel Watzenig, Automated Driving - safer and more efficient future dirving, New York, Heidelberg: Springer International, 2016.

[17] BMVIT, Austrian RDI Roadmap for Automated Vehicles, Vienna: Austrian Ministry for Transport, Innovation and Technology, 2016.

[18] L. N. F. Industrielle, “Comité de Pilotage, “Nouvelle France Industrielle – Véhicule Autonome”,” La Nouvelle France Industrielle, 16 07 2015. [Online]. Available: http://www.pfa-auto.fr/wp-content/uploads/2016/03/Objectifs-de-recherche-Vehicule-Autonome.pdf. [Accessed 14 08 2017].

[19] E. Commission, “Commission Delegated Regulation on the specifications on cooperative intelligent transport systems under Directive 2010/40/EU ("ITS Directive) - Inception Impact Assessment Areas (2017 / 2592333),” European Commission, Brussels, 2017.

[20] European Commission, European Transport Ministers and ACEA, “Declaration of Amsterdam, Cooperation in the Field of Connected and Automated Driving,” ACEA, Brussels, 2016.

[21] E. Commission, “Towards clean, competitive and connected mobility: the contribution of Transport (Staff Working Document),” European Commission, Brussels, 2017.

20.2. References for chapter 0

[1] Gartner Technology Research, Gartner Says Worldwide Information Security Spending Will Grow 7 Percent to Reach $86.4 Billion in 2017, URL: http://www.gartner.com/newsroom/id/3784965

[2] IHS Automotive, Automotive Cybersecurity and Connected Car Report, August 2016, URL: http://www.ihssupplierinsight.com/shop/product/5002659/automotive-cybersecurity-and-connected-car-report

[3] KPMG survey report, “Crossing the line: Staying on the right side of consumer privacy”, November 2016, URL: https://home.kpmg.com/sg/en/home/media/press-releases/2016/11/companies-that-fail-to-see-privacy-as-a-business-priority-risk-crossing-the-creepy-line.html

[4] Ariel Hochstadt, VPN Mentor Survey, VPN Use and Data Privacy Stats for 2017, URL: https://www.vpnmentor.com/blog/vpn-use-data-privacy-stats/

[5] European Commission, ICT Standardisation Priorities for the Digital Single Market, April 2016, URL: http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=15265

[6] European Political Strategy Centre, *Building an Effective European Cyber Shield*. EPSC Strategic Notes, Issue 24, 8 May 2017.
[7] Ponemon Institute, 2017 Cost of Data Breach Study. Global Overview. June 2017.

[8] Digital Single Market news, "European Commission will launch €1 billion quantum technologies flagship". From https://ec.europa.eu/digital-single-market/en/news/european-commission-will-launch-eu1-billion-quantum-technologies-flagship, May 17th, 2016. Retrieved Aug 14th, 2017.

[9] Gartner Technology Research, Gartner Says 6.4 Billion Connected "Things" Will Be in Use in 2016, Up 30 Percent From 2015, URL: http://www.gartner.com/newsroom/id/3165317, Nov. 10, 2015

[10] REGULATION (EU) 2016/679 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation), URL: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0679&qid=1490179745294&from=en

[11] DIRECTIVE (EU) 2016/1148 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union, URL: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016L1148&from=EN

21. Acronyms used in the document

Acronym	Meaning
3D-IC	3-Dimensional Integrated Circuit
5G	5th Generation wireless communication network
AC/DC	Alternating current to Direct Current
AD	Automated Driving
ADAS	Advanced Driver Assistance System
AI	Artificial Intelligence
AIOTI	Alliance for Internet of Things Innovation
AR	Augmented Reality
AUTOSAR	AUTomotive Open System Architecture
BCI	Brain Computer Interface
BIST	Build-In Self-Test
CMOS	Complementary Metal Oxide Semiconductor
CNT	Carbon Nano Tubes
COTS	Components of the Shelf
CPPS	Cyber Physical Production Systems
CPS	Cyber-Physical System
DC/AC	Direct Current to Alternating current
DDoS	Distributed Denial of Service
DfR	Design for Reliability
DfT	Design for Test
DfX	Design for X, where X can stand for Manufacturing, Reliability, etc...
DoE	Design of Experiment
DRAM	Dynamic Random-Access Memory
DRM	demand/response management
DSL	Domain Specific Language
DSP	Digital Signal Processor
DUV	Deep Ultra Violet
ECS	Electronic Component and System
EDA	Electronic Design Automation
EE	Electric and Electronics
EMC	Electro-Magnetic Compatibility
EMI	Electromagnetic interference
ESD	Electrostatic discharge

Acronym	Meaning
ETSI	European Telecommunications Standards Institute
EUV	Extreme Ultra Violet
EV	Electric Vehicles
eWLB	Embedded Wafer Level Ball grid array
FD-SOI	Fully Depleted Silicon-On-Insulator
FDX	??
FPGA	Field-programmable gate array
GALS	Globally asynchronous locally synchronous
GaN	Gallium nitride
GDP	Gross Domestic Product
GPS	Global Positioning System
GPU	Graphics Processing Unit
GSM	Global System for Mobile Communications
HMI	Human Machine Interface
HPC	High-Performance Computing
HPU	Holographic Processing Unit
HW	Hardware
HW/SW	Hardware / Software
IC	Integrated Circuit
ICT	Information and Communication Technologies
IEA	International Energy Agency
IERC	the European Research Cluster on the Internet of Things
IGBT	Insulated-Gate Bipolar Transistor
III-V	Chemical compound of materials with 3 and 5 electrons in the outer shell respectively
IoT	Internet of Things
IP	Intellectual Property / Internet Protocol (depending on context)
IRDS	International Roadmap for Devices and Systems
ITAR	International Traffic in Arms Regulations
ITRS	International Technology Roadmap for Semiconductors
ITU	International Telecommunication Union
LAE	Large Area Electronics
LE	Large Enterprise
LED	Light-emitting diode
LV	Low Voltage
M2M	Machine to Machine

Acronym	Meaning
MC	Major Challenge
MDM	Multi-Dimensional Metrology
MEMS	Micro Electro Mechanical Systems
MEPS	minimum energy performance standards
MIL	United States Military Standard
ML	Machine Learning
MM	More Moore
MMI	Machine to Machine Interface
MNBS	Micro Nano Bio System
MOEMS	Micro-Opto-Electro-Mechanical System
MR	Mixed Reality
MtM	More than Moore
MV	Medium Voltage
NAND	Negative-AND is a logic gate which produces an output which is false only if all its inputs are true
NEMS	Nano Electro Mechanical Systems
NIS	Network and Information Systems
NVM	Non-Volatile Memory
OEM	Original Equipment Manufacturer
OSAS	Obstructive Sleep Apnea Syndrome
PAD	Productivity Aware Design
PCRAM	Phase Change Random Access Memory
PE-ALD	Plasma Enhanced Atomic Layer Deposition
PFSI	Physical and Functional Systems Integration
PHM	Prognostic Health Management
PMIC	Power Management Integrated Circuit
PoC	Point of Care
PoF	Physics of Failure
PSD2	The revised European Payment Services Directive
PV	Photo Voltaic
R&D&I	Research and Development and Innovation
RF	Radio Frequency
RRAM	Resistive Random-Access Memory
Safety	Protecting from any malfunction that might occur
SCM	Storage Class Memory: A non-volatile memory technology that is capable of replacing hard disks.

Acronym	Meaning
SDN	Software Defined Network
Security	Protection from the negative influences of the outside world
SiP	System in Package
Si-Photonics	Silicon-Photonics is the study and application of photonic systems which use silicon as an optical medium.
SME	Small and Medium Enterprise
SMTBF	System Mean Time Between Failures
SoA	Safe operating Area
SoC	System on Chip
SoS	System of Systems
SSI	Smart System Integration
STDP	Spike-Timing-Dependent Plasticity
STEM	Science, Technology, Engineering and Mathematics / Scanning Transmission Electron Microscopy (depending on context)
STT-RAM	Spin-transfer torque random-access memory
SW	Software
TAM	Total Available Market
TEV	Through Encapsulant Via
TIM	Thermal Interface Materials
TRL	Technology Readiness Level
TSV	Through Silicon Via
UCTE	European Network of Transmission System Operators for Electricity
ULP	Ultra-Low Power
V&V	Verification and Validation
VC	Venture Capitalist
VOC	Volatile Organic Compounds
VR	Virtual Reality
VRE	variable renewable energy
WBG	Wide Bandgap Semiconductors
WLP	Wafer Level Packaging