

RAPPORT

# Roadmap for Smarter Electronics Systems

**September 2016**



**Rapporten är sammanställd av:**

Jerker Delsing, Luleå Tekniska Universitet  
Jonas Gustafsson, Luleå Tekniska Universitet  
Magnus Svensson, Acreo Swedish ICT AB  
Leif Lungqvist, Acreo Swedish ICT AB  
Maria Månsson, Svensk Elektronik  
Pierre-Yves Fonjallaz, PhotonicSweden  
Hans Grönqvist, Swerea IVF AB

# Preface

This report is part of Smarter Electronic Systems, a strategic innovation program working for increased competitiveness and growth in Swedish enterprises producing electronic systems or manufacturing products with electronic systems inside. Work is done in broad collaboration between industry representatives, research institutes and universities.

What we call "smarter electronic systems" includes smart hardware based on electronics (pcb-based or micro-/nanoelectronics), photonics, power electronics, sensors, printed electronics, high speed communication electronics, embedded systems and combinations thereof. Electronic systems operate highly cross sectional. They are included in more and more contexts and form an increasingly important share of products and production systems that exist and develop within various sectors. This increases the market for electronic systems.

The demand for smart electronics increases as the need to find new and effective solutions to meet the global challenges facing the world, such as requirements on the development of renewable energy, improving the efficiency of energy production, energy saving, environmental sustainability and care for a growing and increasingly aged population.

For Sweden and Swedish actors to be competitive in smart electronics in the future we need to face three main challenges:

## **Value chain**

Improve collaboration and increase efficiency in Swedish value chains

## **Excellence areas**

Maintain and further develop excellence in the above mentioned areas of electronics

## **Skill supply**

Establish secure skill supply for the Swedish electronics industry

An important part of this work is the monitoring of trends and developments in all these areas. This roadmap is compiled with the aim of being a guideline for Swedish companies in their strategic planning.

# Executive summary

This roadmap targets research and innovation in Sweden in the field of electronics and systems. The intention of the roadmap is to support long-term, 2025-2030, high-level objectives in the field of electronics and systems of world-class Swedish companies, attractiveness, efficient RDI value chains, and combined with a supportive educational system providing competent people to the market.

Background material for this roadmap comes from open business statistics, interviews with more than 200 companies, related roadmaps and workshops with a mixture of industrial and academic participation featuring more than 200 people. The industrial top levels' needs identified in this way are:

- Optimised production with fully automated processes
- Efficient, reliable development processes
- Efficient value chains
- Availability of competence, short- and long-term

Regarding Swedish industry's structure, its position in the world market and identified needs, the roadmap proposes the following high-priority research and development areas:

- Advanced electronics production,
- Embedded systems,
- Photonics,
- Power electronics,
- Micro- and nano-electronics, and
- Reliability

Visions and goal are presented for each of these trends.

To foster development of fundable projects, a number of ideal concepts have been developed. For each ideal concept, a vision is stated, together with which trends are addressed and how the long-range objectives are supported. For each ideal concept, concrete action and identified business potential are provided that aim to guide the development of RDI projects that will provide an input to the high-level objectives and the top-level industrial needs. The ideal concepts developed are:

- Optimised production with a high degree of automation
- Right competences in the short and long term
- Efficient value chains
- Availability of test, pilot, and verification labs
- Technology uptake

# Contents

<b>1. Introduction</b>	<b>6</b>
<b>2. Electronics, components and systems in the European industry</b>	<b>7</b>
2.1 Comparison between Sweden and Europe	8
<b>3. Methodology</b>	<b>9</b>
<b>4. Identified Research and Development areas</b>	<b>11</b>
4.1 Advanced electronics production	12
4.1.1 Identified trends	12
4.1.2 Goals & Visions	13
4.2 Embedded systems	13
4.2.1 Identified trends	14
4.2.2 Goals & Visions	14
4.3 Photonics	15
4.3.1 Identified Trends	16
4.3.2 Goals & Visions	16
4.4 Power electronics	16
4.4.1 Identified trends	18
4.4.2 Goals & Visions	18
4.5 Micro- and nano-electronics	19
4.5.1 Identified trends	20
4.5.2 Goals & Visions	21
4.6 Reliability	21
4.6.1 Identified trends	22
4.6.2 Goals and Vision	22
4.7 Industrially interesting/emerging technologies	23
4.7.1 Identified trends	24
4.7.2 Goals & Visions	25
<b>5. A selection of prioritised ideal concepts</b>	<b>26</b>
5.1 Optimised production with high degree of automation	27
5.1.1 Vision	27
5.1.2 Description of Ideal Concept	27
5.1.3 Trends Supported by the Ideal Concept	27
5.1.4 Visions and Long-Range Goals supported by the Ideal Concept	28
5.1.5 State-of-the-art Analysis	28
5.1.6 Proposed Actions	28
5.1.7 Business Potential	28

5.2	Right competences short and long term	28
5.2.1	Vision	28
5.2.2	Description of Ideal Concept	28
5.2.3	Trends Supported by the Ideal Concept	29
5.2.4	Visions and Long-Range Goals supported by the Ideal Concept	29
5.2.5	State-of-the-art Analysis	30
5.2.6	Proposed Actions	31
5.3	Efficient value chains	31
5.3.1	Vision	31
5.3.2	Description of Ideal Concept	31
5.3.3	Trends Supported by the Ideal Concept	32
5.3.4	Visions and Long-Range Goals supported by the Ideal Concept	32
5.3.5	State-of-the-art Analysis	32
5.3.6	Proposed Actions	33
5.3.7	Business Potential	34
5.4	Availability of test, pilot and verification labs	34
5.4.1	Vision	34
5.4.2	Description of Ideal Concept	35
5.4.3	Trends Supported by the Ideal Concept	35
5.4.4	Visions and Long-Range Goals supported by the Ideal Concept	35
5.4.5	State-of-the-art Analysis	35
5.4.6	Proposed Actions	36
5.4.7	Business Potential	36
5.5	Technology uptake	37
5.5.1	Vision	37
5.5.2	Description of the Ideal Concept	37
5.5.3	Trends Supported by the Ideal Concept	37
5.5.4	Visions and Long-Range Goals supported by the Ideal Concept	37
5.5.5	State-of-the-art Analysis	38
5.5.6	Proposed Actions	38
5.5.7	Business Potential	39
<b>6.</b>	<b>Main sources of information</b>	<b>39</b>

# 1. Introduction

Electronics, components and systems is a Swedish national strategic research and innovation area. The Swedish name is “Smartare elektroniksystem” and the English name is ECS Sweden. ECS Sweden is rooted in a research and innovation agenda developed in close collaboration between industry and academia in 2014 [1]. The strategic research and innovation areas are supported by Vinnova. Vinnova also provides funding for strategic projects and research projects selected in open calls. Funding is at a level of €4-6M per year. To guide the selection of strategic research projects and work programmes for open calls, the following roadmap has been developed.

The objectives for 2025 that the roadmap should support are:

1. Sweden will be a world-class electronics and system nation with Swedish companies at the very forefront of the global market.
2. Sweden as a country will be an attractive prospect for companies of all sizes that are dependent on electronics, as here there is a geographical proximity to flourishing research and industry which, with their efficiency and niche expertise, provide solid anchoring for companies by offering an advantageous climate in which to operate.
3. The efficiency of electronic systems R&D&I is guaranteed by solid collaborative functions between all

actors involved in competence and value chains.

4. The area of smart electronic systems is supplied with competent personnel by an education system that has strong ties with both research and industry via relevant subjects, pronounced elements of “industrial reality” in undergraduate education and the potential for academic development.

This document is the first version of the ECS Sweden roadmap and is slated for biannual updates. The method used to develop the roadmap is based on a method used for several years within VTT Finland and is described in chapter 3.

This roadmap document is structured as two main chapters. In chapter 4, trends, visions and long-range goals are formulated and categorised into a set of research and development areas. In chapter 5, visions and long-range goals are concretised into a number of ideal concepts that form the direction of development proposed in the roadmap. Each ideal concept contains a description of the current state-of-the-art, the business potential, and a set of proposed actions to attain the ideal concept. There is always a close connection to the aforementioned research and development areas. In addition, the roadmap is summarised with concluding remarks and project proposals. More than 200 in-depth interviews have been held with companies. The interview results in

combination with state-of-the-art as found in other roadmaps and reports make up the underlying material for the roadmap [2]. The in-depth analysis of this material by a group of researchers and industrial experts has strongly influenced the roadmap. We hope that the roadmap will inspire different R&D

stakeholders so that Sweden can realise projects that meet the key industries' challenges arising out of the long-term objectives listed above.

Presentations, documents and more information can be found at:  
<http://www.smartareelektroniksystem.se>

## 2. Electronics, components and systems in the European industry

Major strategies are currently emerging on the European scene. The Digitisation strategy is strongly promoted at the political level. The industry's response is Industry 4.0. Both of these are supported by new technologies such as the Internet of Things, IoT, and System of Systems, SoS. In combination, they are contributions to Smart Systems and Smart Everywhere. All these technologies have their roots in electronics and embedded system software.

Europe has for a long time been the clear world-leader in embedded system software. This is underpinned by the leading position Europe has in many areas characterised by system integration, such as telecom (e.g. Ericsson, Nokia), automotive (e.g. VW, Daimler, BMW, Volvo), automation (e.g. ABB, Siemens, Schneider, Metso), aeroplanes (e.g. Airbus, GKN), railway (e.g. Siemens, Bombardier), and energy (e.g. Schneider, ABB, Siemens). All these industrial markets are characterised

by very extensive, and still increasing, use of embedded software. The rate of software-based technology development and related market changes is in most cases clearly faster than in other industries. This means that industrial and academic capacity must be at the forefront of software technology. The major industrial actors and their supplier networks also currently have competence and capacity to absorb the next generation of software technologies developed in academia.

On the hardware side, Europe is an underdog. Chip companies like NXP, Infineon and ST-Microelectronics may lead in niches but are small compared to giants like Intel, Samsung, TSMC, etc. European electronics hardware production is specialised at production volumes below 1 million units per year and mainly addresses the industrial market.

It is clear that Europe has lost most of the consumer product market to Asia

and the USA. In the consumer market, we find some excellent exceptions like Electrolux and Philips.

Europe has comparatively extensive academic competence in integrated circuits and supportive technology, but this is more limited when it comes to electronics production. The match between industrial requirements and academic competence and capacity is not ideal. It is clear that general industrial capacity and competence to absorb the next generation of hardware technologies is not at the same level as for software.

The electronics, components and systems industry is often depicted as shown in Figure 1, where approximate market values are also indicated. Another feature of the industry is that it is

geographically evenly distribute across the continent.

To support its industry Europe has created ESCEL, an almost €5bn commitment on Electronics Components and Systems jointly funded by the EC, 24 countries and the industry. The ambition is to exploit the synergies between hardware and software to further enhance Europe's position in the fields. In parallel Europe has other support programmes, e.g. PENTA (chip technologies), ITEA-III (large software systems), and Photonics21 (PPP within H2020). In addition to these more focused ambitions related to electronics and software, most other parts of the European H2020 programme have needs in for particular software to meet the objectives.

## 2.1 Comparison between Sweden and Europe

Comparing Sweden to Europe reveals some interesting differences. The company structure in Europe is like a pyramid: many small enterprises, fewer medium size enterprises and few large enterprises. The situation in Sweden is different. Here the number of medium size enterprises is much lower than in Europe.

In chip-making and related technology, Europe is not a giant but notable is the almost total absence of chip-makers and related technology in Sweden.

Regarding the value chain in the electronics, components and systems business, it is also notable that both Europe and Sweden have very few printed wire board manufacturers. Both

the European and the Swedish contract assembly industry have seemingly lost high volumes (+1m units per year) to Asia.

On the embedded software side, Europe and Sweden are both in world-leading positions with Sweden clearly among the top nations in Europe. This can be largely attributed to the good number of very large enterprises in Sweden and their position as major system vendors in their respective markets. In addition, these major vendors also rely on a large number of specialised embedded software SMEs.

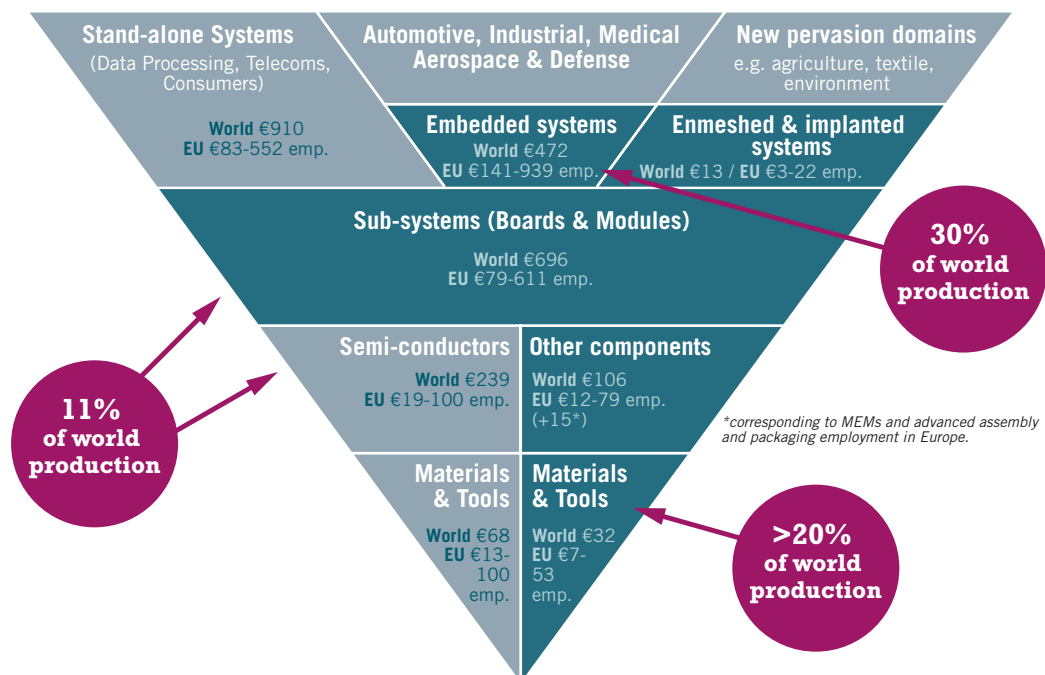


Figure 1: The electronics, components and system industry pyramid with indications of market values and the European market share.

### 3. Methodology

Roadmapping is a methodology that helps companies and entire industries assume anticipated future changes and illustrate market trends, environmental changes, and technology life-cycles [3]. However, roadmapping is not a tool for predicting the future; it enables strategic planning and helps decision-makers craft decisions that can achieve the most desirable outcome [4].

This work applies a roadmapping method developed in VTT [5]. It organises the efforts into several steps,

as illustrated in Figure 21. The first step is the development of a vision, i.e. the ideal situation where the end user requirements are satisfied. Vision-building consists of defining the overall vision, recognising the general trends and drivers, and how the observer's own vision is affected by them. The next step is the definition of the long-term objectives that enable the vision. After the long-term objectives, the current state and the steps required to achieve the long-term objective are defined.

To define the context for the roadmap, an overview of the areas of interest must be defined. The business environment and the relevant overall development trends must be selected for the electronics components and systems domain to identify the development directions of the roadmap and the eventual concluding recommendations. The relevant trends are presented in chapter 4.

As for the scope of the roadmapping, the relevant general industrial needs as

defined by the 2025 objective have been selected. These needs are based on the identified trends and needs from which a set of high-level goals are defined; they are further transformed into more concrete actions, which are referred to as ideal concepts. These ideal concepts form the vision required to implement the roadmapping work. The ideal concepts are presented in chapter 5.

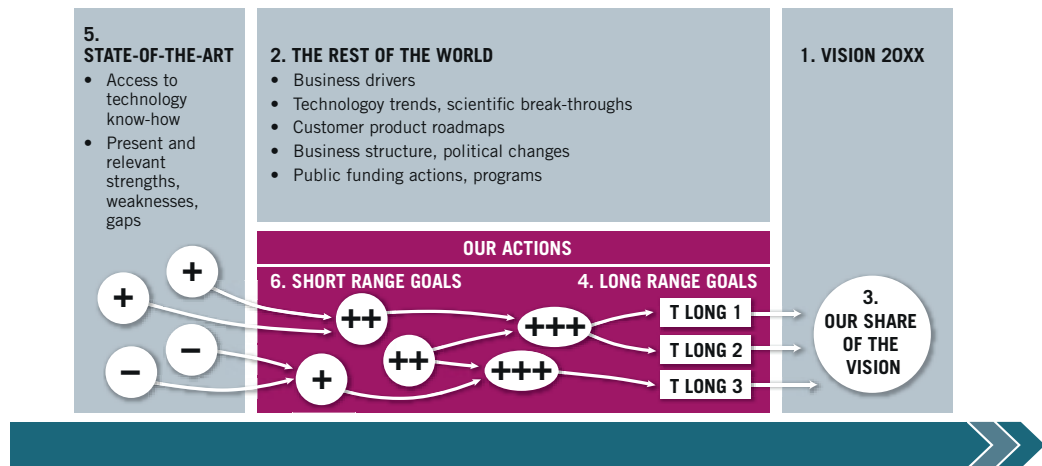


Figure 2: Roadmapping phases [5].

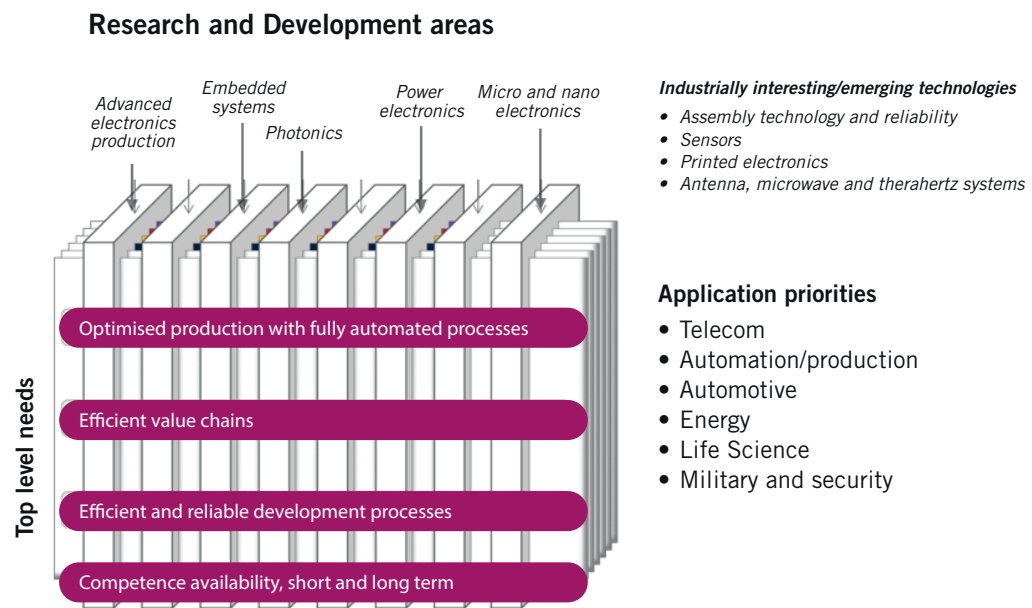


Figure 3: Top-level industrial needs with research and development areas important for prioritised national application areas.

## 4. Identified Research and Development areas

As described in chapter 3, a well-defined description of the current business environment and trends is required to identify the development directions of the roadmap and the eventual concluding recommendations.

The business environments and their application markets identified by the Swedish ECS agenda [1] are:

- Telecom
- Automation/Production
- Automotive

- Energy
- Life Science
- Military and Security

With these application markets in mind, global trends have been identified and placed into the scope of the Swedish electronics, components and systems industry. An important input to the categorisation comes from the industry needs survey [2]. An initial categorisation of top-level needs, ongoing trends, and

top-level application areas is shown in Figure 3.

A number of R&D areas are identified below. It is clear that there are clear complementarities between these areas but jointly they support one or several of the four industrial top-level needs:

- Optimised production with fully automated processes
- Efficient, reliable development processes

- Efficient value chains
- Availability of competence, short- and long-term

Based on the identified R&D areas and top-level needs, a set of high-level goals are defined. In the following sections, the R&D areas and goals will be described, and in later sections these will be transformed into more concrete actions, referred to as ideal concepts in chapter 5.

## 4.1 Advanced electronics production

Electronics production has to a large extent been outsourced from Europe and Sweden to Asia and China in particular. Europe and Sweden thus currently have limited capacity for and knowledge of high-volume manufacturing of electronics.

The electronics assembly industry addresses low to medium volume high-grade industry electronics products. The industry uses mainstream technology and is clearly not using the more advanced technologies used in high-volume production of consumer products.

The survey clearly indicates that advanced production technologies for making and introducing advanced automation with high reliability are considered to be key to remaining competitive in the market.

An inspiring example is AutoLiv which aims for multi-million units using product-tailored automation in combination with advanced materials.

The identified trends in respect of production efficiency and platforms, products, and services are shown below.

### 4.1.1 Identified trends

- Industri 4.0
- Re-industrialisation of Europe
- Extensive and late customisation of products, software configurations
- Additive manufacturing for electronics integration in things, e.g. printed electronics
- Further miniaturisation at PCB and component level
- Increased reliability requirements (HW and SW)
- Application of electronics in challenging environments
- Total production lead time of increasing importance
- The high importance of production knowledge and capacity
- High flexibility in small quality production – customisation and single unit production
- IPR becoming increasingly important
- Increased use of automation, e.g. cameras for inspection

#### 4.1.2 Goals & Visions

- Increased end-product reliability
- New disruptive production technologies enabling Swedish and European leadership in electronics production
- Close the technology gap between silicon and PCB
- Automation for flexible and efficient electronics production
- Sufficient supply of competent personnel
- Increased electronics life time in challenging environments

## 4.2 Embedded systems

Embedded systems are software technologies and associated processor platforms. We find embedded systems everywhere, built into cars, roads, railways, bridges and tunnels, in medical systems and devices and surgical robots, in homes, offices and factories, in satellites and aeroplanes, at airports, in mobile phones and communication and virtual reality glasses, and even in our clothes. They are interconnected in networks of many devices – from the car to the fixed road infrastructure, the smart card to the banking and payment systems and use of public services.

Embedded Systems technologies are deployed in all market sectors – automotive, aerospace, trains, healthcare, energy and environmental management, communications, entertainment, textiles, manufacturing, transport, logistics, printing, chemicals, agriculture, food & drink, timber and materials. Annual growth is more than 10% and over 400 billion devices are expected worldwide by 2025. Moreover, the value added to the final product by embedded software is often orders of magnitude higher than the cost of the embedded devices themselves.

As they pervade all artefacts of life, from children's toys to space probes, the more of the value of those artefacts will be derived from their embedded intelligence. In parallel, the dependable and safe operation of those artefacts will increasingly depend on the proper design and operation of embedded systems. Greater public awareness about their dependence on embedded systems will raise expectations as well as concerns about potential failures and safety, privacy and security, so the quality and reliability of embedded systems are key issues.

Across various application contexts, three research domains were identified to form a second major research challenge dimension: Reference Designs and Architectures, Seamless Connectivity and Middleware, and System Design Methods and Tools. Furthermore, the networking of embedded systems was identified as a major future trend that would reshape the world of embedded systems from a collection of independent or locally connected computers to large interconnected systems.

The emerging use of the Internet for embedded system networking provides new opportunities. Embedded systems

will be able to exploit the emerging ubiquitous network topology not only for communication but also to gain access to the knowledge of Internet based information systems. In turn, information systems will utilise embedded systems as sources of information to enable the Internet of Things.

Networked embedded systems will in effect become the neural system of society. Embedded systems technology should therefore no longer be considered in isolated application contexts but should be seen in relation to their contribution to the evolution of society and, in particular, to their contribution to addressing today's and tomorrow's societal challenges.

This increasing dependency on embedded software technology comes with risks connected to ICT security and society, and commercial and personal harm that can be caused by intentional or unintentional actions. The embedded software security and the interaction with related hardware thus become a very important technology and business issue.

Some well known and famous attacks are Stuxnet, the Jeep that was hijacked, and numerous thefts of personal data. There are interesting sites which log various attempts to attack machines globally, see for example: <http://map.honeynet.org>. The numbers are very high! In the United Kingdom, a survey the government performed showed that the average cost of a cybersecurity breach more than doubled in 2014 compared to 2013, rising from £600,000 to £1.46 million. An estimate from 2015 shows that cybercrime costs the UK £27 billion annually.

#### **4.2.1 Identified trends**

- Importance of platforms and reference designs
- Seamless connectivity and semantic interoperability
- Importance of design methodologies and tools to reduce time to market
- The intelligent capabilities offered by networked and integrated embedded systems
- Internet of Things
- Systems of Systems
- Internet of Things and everything sensible connected also mean that cybersecurity needs careful attention.
- The smart environments that are envisaged will create completely new possibilities to develop applications and services
- That embedded systems technologies are critically important in redressing the present imbalance in productivity growth between Europe and the USA and Asia
- Increased demands for reliability of code and electronic hardware
- Reuse of code and platforms
- Evolutionary systems
- Connected sensors enabling automation
- High competition for competent and skilled workforce
- Increasing system level risk when disconnecting from lower level software and the hardware

#### **4.2.2 Goals & Visions**

- Multiple competence centres for embedded systems
- Cooperation clusters for value chain integration

- Improved quality and reliability of code and electronic hardware
- Evolvable software
- Seamless interoperability at service level
- Cybersecurity needs to be an integrated part of any development work from day one
- Methodologies and tools for System of Systems engineering
- Hardware aware software design

## 4.3 Photonics

Photonics is the “engineering applications of light”, involving its use to detect, transmit, store, and process information, to capture and display images, and to generate energy. Photonics technology is central to modern life. It enables today’s Internet as well as today’s mobile communication. It enables the manufacture and inspection of all the integrated circuits in every electronic device in use. It gives us displays, optical fibres, advanced precision fabrication, sensors and medical diagnostics tools. Photonics technology has the potential for even greater societal impact over the next few decades. Solar power generation and new efficient lighting could for example transform our energy landscape. New optical technologies will be essential to supporting the continued exponential growth of the Internet. The broad deployment of optical sensors, not least in industrial environments, will considerably enhance our ability to adjust processes and will enable significantly smarter production and manufacturing. Photonics is in more and more products, in some cases visible for the users, but generally invisible. One famous example to illustrate what has taken place in recent years is the smartphone. One can remember what mobile phones

looked like ten years ago: A greenish liquid-crystal display was where you could find photonics at that time. Today, a rather standard smartphone has a high-resolution display, one or two multi-megapixels cameras, and a powerful LED lamp. In addition, the use of high-precision lasers allows today’s smartphones to be made sufficiently lightweight.

At the European level, the European technology platform, Photonics21, has formed a Private Public Partnership with the European Commission to enable funding of research and innovation projects that have a photonics focus. In 2009, a report [6] highlighted the strong economic impact of photonics in Europe and world-wide. Following that, photonics was selected by the EU commission as one of six Key Enabling Technologies (KETs)[7].

Photonics is much less mature than electronics but is expected to make significant contributions to innovation and impact on key societal challenges over the coming decades. The slogan “The 20th century was the century of the electron, the 21st century will be the century of the photon!” puts this into perspective.

#### 4.3.1 Identified Trends

- Photonics has a strong growth rate globally, and also in Europe and in Sweden [8].
- Two application areas have a particularly strong global growth rate: clean tech and medicine and health (respectively called green photonics and biophotonics. In Sweden, the field of automation is yet another area where strong growth is expected) [9].
- Most Swedish photonics companies have a strong export ratio and a strong global growth rate is therefore in principle exploitable.
- More interdisciplinary approaches are required for most advanced new products. This is especially true as regards health applications.
- Increased miniaturisation. Integrated photonics circuits are intimately combined with advanced nano-electronic circuits and sometimes with bio-devices through micro-fluidics.
- Increased integration of photonics and embedded systems software
- Solar cells as a European market opportunity
- Robust sensors based on photonics technology

#### 4.3.2 Goals & Visions

- Create a viable platform for cooperation between photonics and medical professionals.
- Photonics solutions for highly efficient and flexible production with integrated quality assessment.
- Low-cost high-performance products for 5G based on photonics hardware, in particular for use of higher carrier frequencies (mm-waves).
- Highly competitive integrated devices empowered by photonics (including micro- and nano-electronics, embedded systems and/or e.g. bio-systems).
- Intelligent Human Centric Lighting solutions combined with IoT for multiple purposes: communication, health and energy efficiency.
- Leading-edge network and video surveillance based security solutions.
- High performance near- and mid-infrared (NMIR) equipment for imaging and sensing applications brought to the consumer market, through reduced cost, size and user complexity.

### 4.4 Power electronics

Power electronics refers to electronic devices and systems used to transform electric energy. Power electronics is used to transform direct (DC) and alternating (AC) voltages and currents (DC to DC and DC to AC and AC to DC) in a variety of applications from power supplies, motor drives in industrial applications (fans,

pumps, compressors and conveyers), high-frequency resonant converters, heat pumps, elevators, automotive (hybrid and electric vehicles) and traction to generation, transmission and conditioning of electric energy (HVDC, FACTS).

Energy saving, improved energy efficiency and environmental protection

have become top-priority political issues in Europe. The demand for electricity is expected to grow much faster compared to other energy sources by 2050. The consumption of electrical energy is predicted to grow from 40% to over 60% of all energy consumption. It will be a matter of urgency to reduce consumption by increasing efficiency, mainly by reducing losses in the electrical power systems, and to reduce dependency on fossil and nuclear energy sources by increased use of renewable energy. Power electronics assumes a key role in this perspective.

Power electronics is the key technology in controlling the flow of energy from source to load. The share of total electrical energy in industry, transportation and home and office appliances which is controlled by power electronics, e.g. in variable speed drives (AC motors) is estimated to increase from 40% in 2000 to 80% in 2015.

Power electronics is also the enabling technology for efficient use, distribution and generation of electrical energy. Advanced power electronics could realise savings of more than 50% in energy losses in converting from mains or battery voltages to those used in electronic equipment if more widely used.

Some specific examples of savings potential and key role of power electronics are:

- a. in power supplies by reduction of losses and stand-by consumption,
- b. in motor drives by using power electronics controlled AC motors,
- c. in home appliances by use of electronic thermostats in refrigerators and freezers, power electronics

- d. control of compressor motors and reduction of stand-by consumption,
- d. in lighting by control of fluorescent and High Intensity Driving ballasts,
- e. in intelligent buildings by control of lighting and occupancy sensing,
- f. by connecting the renewable energy sources (solar and wind) to power grid,
- g. in automotive applications in power trains of hybrid and electric vehicles [10].

Over the past 30 years there has been a continuous increase in power density of electric systems in kW/m<sup>3</sup> equivalent to reduced volume and weight of equipment. Development has been driven by increasing the efficiency of the systems through improvements in power devices and in packaging and power module technologies. The dominating improvements have been in the conducting and switching properties of the power devices, resulting in lower losses. In packaging and module technologies, improvements have been related to heat removal through new packaging materials and cooling technologies. New heat-sink designs facilitated by new technologies ( $\mu$ -channels, pin fin, 3D-printing) and double sided cooling eliminating wire-bonds all make it possible to handle higher dissipated power. Innovations in die attach (nano-silver, diffusion bonding) and interconnect technologies (Cu, ribbons, "Flex" technology (Infineon)) improve the robustness of power modules and facilitate higher operating temperatures and thus higher power density.

#### 4.4.1 Identified trends

We stand at the threshold of a paradigm shift in power electronics systems. It stems from the fact that sustainable development in the global perspective is linked to the increased role of electric energy and increased utilisation of the power electronics systems. This development will be accelerated by the transition to the next generation technology with silicon devices being gradually replaced by wide band-gap materials like silicon carbide and gallium nitride. The transition to the silicon carbide material and technology will revolutionise power electronics systems by facilitating low loss, more efficient and more compact systems. It will fuel the spread of power electronics systems into new areas and contribute essentially to the reduction of CO<sub>2</sub> generation globally.

- Climate changes followed by political goals for energy reduction and increased use of renewable energy
- Small continuous improvements in power density due to smaller components (More Moore), improved cooling and smarter construction methods will continue
- Further integration of control electronics and power module technology
- Disruptive changes by use of wide band-gap materials, e.g. SiC and GaN. A SiC transistor has 400 times lower inner resistance compared to a Si transistor. Transition to these new materials means at least one order of magnitude higher power density on system level, elimination of the

recovery charge and at least 50% reduction of switching losses

- Increasing switching frequency in order to reduce size and weight of equipment
- Ultra-low inductance modules and packages to facilitate fast switching
- SiC and GaN can be operated at higher temperatures, moving the temperature limit from the component to the package, encapsulation or entire product
- New wide band-gap materials, SiC and GaN, in low cost applications, consumer products
- Tools for co-simulation and co-design for electrical and thermal properties
- Large-scale power grid integration
- Increased dynamics in power distribution
- Increasing number of measurement and control points in grids
- Need for power grid monitoring and control to prevent outages
- Need for grid monitoring and control to support load balancing and energy savings

#### 4.4.2 Goals & Visions

- A general loss reduction of at least 50% in the power electronics applications by using more efficient power electronics with SiC
- Wide band-gap materials to replace Si in power converters. SiC devices for voltages  $\geq 1200$  V and GaN for voltages  $\leq 600$  V
- Development of advanced power electronics products and systems for renewable energy sources, electrification of vehicles and transportation and for distributed

- grids will increase exports of Swedish electronic equipment
- Reduced development time due to thermal and electrical co-design
- Strong integration into embedded systems and monitoring and control
- Very large system with power switching and drive control

## 4.5 Micro- and nano-electronics

Micro- and nano-electronics (MNE) is the study, design and application of micro- and nano-scale electronic components and systems. These components are typically, but not exclusively, made from semiconductor materials and involve specialised knowledge domains within physics, materials, manufacturing, design and integration. They provide the foundation for innovation in a broad range of industries and underpin a significant part of the world economy [11]. MNE technology affects all aspects of society and continues to expand beyond traditional semiconductor intensive markets (communications and computer) into all other physical industries, such as automotive, energy, industrial, agriculture, mining – in principle MNE provides the growth engine for the digitalisation and connectivity of the world.

As a result, MNE has been identified by the European Commission to be one of six prioritised “Key Enabling Technologies” essential for growth and jobs in the EU. Efforts to coordinate research in the EU within MNE have taken place within the framework programmes (FP6, FP7, H2020) and in order to make it more industrydriven the EU has established initiatives like Joint Technology Initiatives (ENIAC) and the Eureka Clusters (Catrene, Euripides, Penta) [11].

Sweden has a history of a diverse, strong and innovative industrial base open to the adoption of new technology. Increasingly this new technology will be based on MNE, digitisation and electronic integration. This is because broader parts of Swedish industry will require integration of advanced electronics within new products to remain competitive. Sweden has high academic excellence in many MNE fields, with many excellent researchers combined with world-class research laboratories/clean rooms to build on for the future. The challenge is to link this academic excellence and infrastructure to common Swedish industrial needs and to improve on the application of (publicly funded) MNE research to new products and new business creation.

Within the MNE landscape there are two main driving tracks that characterise technology development and drive innovation – “more Moore” and “more than Moore”:

- **More Moore** – increasing transistor density in actual products through miniaturisation of components at the nano scale along an international roadmap for technology development established by industry, and aiming at higher performance, lower costs and less energy consumption.

- **More than Moore** – diversifying the functions of an integrated circuit or module by integrating sensors, actuators, bio-circuits, power and RF/high frequency within a highly integrated package.

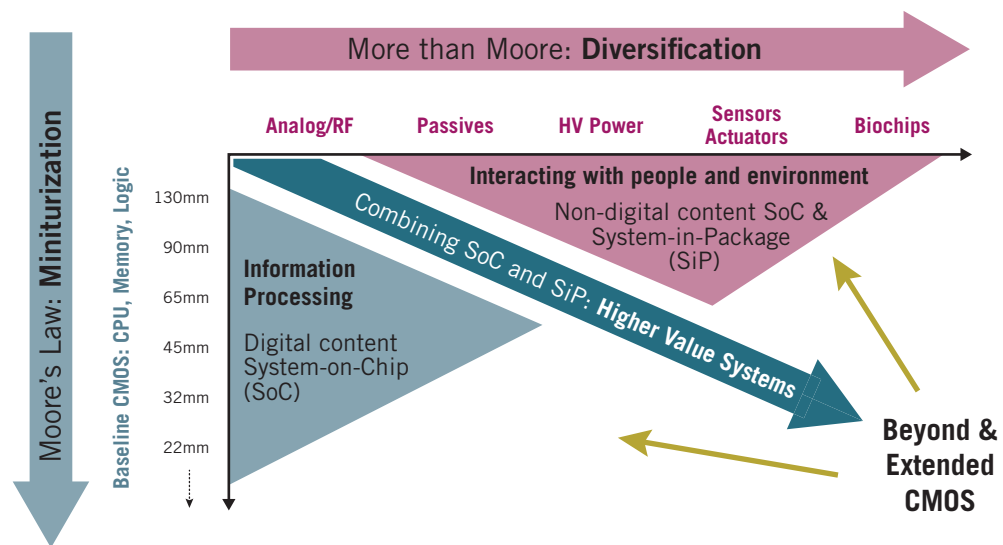


Figure 4: More than Moore: Miniaturisation versus diversification.

#### 4.5.1 Identified trends

- Density scaling of transistors according to Moore's law has since 2007 slowed to 1.6x per node from the original 2x per node.
- Strained silicon, high  $\kappa$ /metal-gate and multigate transistors are now widely used in IC manufacturing and further improvements are expected in III-V materials and Ge as these materials promise higher mobilities than Si devices.
- With system integration centred around mobile communicating devices (handheld), there has been a shift from performance driven IC design to power consumption driven IC design.
- As lithography and 2D scaling will eventually reach fundamental limits towards the beginning of the next decade, both logic and memory devices are exploring the use of the vertical dimension (3D).
- New operating principles for logic and memory devices based on tunnelling (e.g. TFET) or spin offer the possibility of operating at very low power.
- Microelectromechanical system (MEMS) devices are further integrated and thus moving semiconductor main drivers from microprocessors to SOC (system on chip) and SIP (system in package).
- Energy harvesting. With miniaturised and distributed electronic systems everywhere in the world of the Internet

of Things, sustainable power supply to all these systems is dependent on energy harvesting.

- Heterogeneous systems integration is becoming a key enabling technology for a diverse set of new industries (e.g. IoT) that are increasing the use of MNE in their products.
- Ever more complex functionality can be incorporated in wireless systems on chip implemented in advanced CMOS technology, being capable of processing gigabits per second using millimeter wave carrier frequencies, form the basis for upcoming 5G cellular systems.
- European companies, including a large number of SMEs are world leaders in smart microsystems such as health implants and sensing technologies.

#### 4.5.2 Goals & Visions

- Focus on state-of-the-art semiconductor and heterogeneous

systems integration utilising new material (e.g. graphene).

- Devices and systems for Smart Sensors and Systems Integration to meet global challenges and develop systems for Smart Energy and Smart Cities.
- Establish an effective promotional activity to engage Swedish companies to better utilise the funding instruments in ECSEL, EUREKA and the upcoming PENTA. This would include the definition of an organisation to represent Swedish industry's interests at the European level with the goal of facilitating and building Swedish participation in EU-funded projects within the MNE programmes.
- Securing long term national capacity on design of advanced systems on chip. This gives the system design industry a competitive advantage, where custom-designed systems on chip together with the system architecture, algorithms and software provide state-of-the-art performance and unique functionality.

## 4.6 Reliability

Electronics must be designed such that reliability can be guaranteed in the actual working environment of the electronics throughout the expected life time.

From the interview responses it can be concluded that eighty per cent of the interviewees say they have a documented process for verifying the reliability of their products. Further, 88% say that it is clear what party has the responsibility of specifying the relevant tests and who the responsible party is for conducting these tests.

Despite this 67% say there is a need to increase reliability and in particular improve the routines and processes. Extended testing and improved testability of the products were also mentioned by the interviewees. Out-of-specification components was the most common reason behind poor reliability but several others were mentioned: Flaws in verification procedures and quality control, poorly verified software and inadequate communication between

customer and supplier were common reasons.

Many (71%) also experience reliability problems with products, components and software purchased as subsystems.

The most common problems are related to fabrication errors and out-of-specification components as well as poor software quality.

The responses show that there is a need to improve the routines and the processes used for verifying the reliability of the products. There is also a need to improve the routines for tests and quality control.

Important issues are that the relevant tests and standards are not applied in a correct manner. Standards for yesterday's technology are applied to new and untested technologies. Also, lack of competence and poor routines lead to reliability problems in the products.

The industry faces a number of challenges like:

- An education initiative is needed in the industry concerning the methods of ensuring reliability that are based on built-in reliability already in the design phase of the projects.
- Reach an understanding that standardised test methods from, for instance, IPC are not enough to guarantee reliability when new technologies are used.
- Develop methods for reliability assessment based on the principles of "Physics of Failure".
- Take into account how selected design solutions affect the reliability of the end products' producability and how that affects manufacturing cost and reliability.

#### **4.6.1 Identified trends**

- Higher levels of integration, finer pitch
- More I/Os demand new assembly technologies
- High-frequency applications put high demands on precision
- More high-power applications implies that thermal design is included
- Electronics everywhere means new untested environments
- Demand for low cost which is in contradiction to high reliability

#### **4.6.2 Goals and Vision**

- Need for an approach where Physics of Failure is a key element
- New environments for electronics need to be analysed, (thermally, mechanically, etc.)
- Novel assembly technologies need to be tested before critical electronics are deployed
- Capabilities for rapid re-design

## 4.7 Industrially interesting/emerging technologies

In addition to these research and development areas a few runner up areas have been identified. These are:

- **Printed electronics**

Organic and printed electronics are based on the combination of new materials and cost-effective, large area production processes to enable new applications not possible with conventional electronics. A key advantage of organic and printed electronics is the ability to make thin, light-weight, flexible, robust and environmentally friendly electronics products. It also makes possible a wide range of electrical components that can be produced in low cost reel-to-reel processes.

Intelligent packaging, OLED Intelligent packaging, OLED lighting, printed multifunctional systems, rollable displays, flexible solar cells, electronic clothing, disposable diagnostic devices or games, flexible touch screens, and printed energy storage are just a few examples of promising fields of application for organic electronics based on new, large-scale processable, electrically conductive and semi-conducting materials. Due to the myriad applications of organic electronics it can become a key enabler of the future Internet of Everything, in which functionality will be embedded into everyday objects. Organic electronics can be used by itself, but also as part of a hybrid system combining printed and organic components and silicon,

each where they make the most sense. These hybrid systems will be especially important in the next few generations of products.

- **Antenna, microwave and terahertz systems**

Driven mainly by the increased use of handheld wireless devices, laptops, tablets and smartphones, global mobile data traffic has increased exponentially over the past 5 years. Future driverless cars, other autonomous systems and the huge amount of connected devices that will be part of the Internet of Things will continue to drive development. Cisco expects overall data traffic to grow to 24,3 exabytes per month by 2019, an almost tenfold increase over 2014 (Cisco VNI Mobile 2015, white paper). Today's systems do not have the capacity to meet such an increased amount of data traffic and as we run out of spectrum space the pace of wireless progress could slow. The alternative is to move to higher frequencies where there is more space. One of the major benefits of these high frequencies is the very small antenna size that permits many antenna elements to be formed on a common structure to create phased arrays with very high gain to boost transmit and receive power. There are already applications that use millimeter-wave band. One is automotive radars at 77 GHz, where Sweden has a world-leading industry in automotive safety along with academic excellence.

· **Sensors**

A sensor is any device that can take a stimulus, such as heat, light, magnetism, or exposure to a particular chemical, and convert it to a signal. Sensors have been around for a very long time. Temperature sensors thermometers – were developed in the late 16th century and pressure sensors a few decades later. More recently devices have been developed to sense light (photocells), sound (microphones), ground vibrations (seismometers) and force (accelerometers), as well as sensors for magnetic and electric fields, radiation, strain, acidity and many other phenomena. While the concept of sensors is nothing new, sensor technology is undergoing a rapid transformation. The introduction of the iPhone and Wii in 2007 started the mobile sensor tornado. From 2007 until 2013, mobile sensor consumption grew from 10 M to 5.8 billion units (Yole development) and at the same time reducing the price of MEMS devices. Smartphones have only been the beginning; development continues from at least three different directions:

- Smaller: Nanotechnology and MEMS inspire the creation of sensors based on entirely new principles.
- Smarter: The increasing power of microelectronics makes it possible to create sensors with built-in intelligence.
- More mobile: Rapidly spreading wireless technologies allow sensors to send back data from remote locations, or even when they are in motion.

Over the past few years the number of sensing devices per car has doubled and continues to rise as sophisticated but inexpensive sensors become more available. The internet of things will be the internet of sensors. The adjectives “smart” and “connected” are expected to be applied to traditional machinery, wearables, autonomous cars, buildings and many other things.

#### **4.7.1 Identified trends**

· **Printed electronics**

- Hybrid system. A combination of printed, flexible electronics and classic silicon components.
- OPV, organic photovoltaic. OPVs are outperformed by silicon-based PVs in terms of efficiency and lifetime but the form factor offer possibilities to incorporate OPVs in products where conventional PV cannot go.
- OLED lighting and design. The main market for OLED technology today is displays following the path of using (rigid) glass substrates. In this segment, far-east manufacturers are totally dominant. However, form-factor offered by using flexible substrates like metal or plastic foil opens up unlimited possibilities for added value in existing and new products.
- “Green” and sustainability. There are many aspects of green and sustainable electronics. Two examples that can drive implementation of printed and organic electronics are: A clear risk of supply limitations for some metals crucial to traditional electronics;

- from a recycling perspective, organic materials are considered favourable.
- Electronics everywhere, Internet of Things.
- Brand protection. As one of the first companies in the world, Sweden-based ThinFilm Electronics now offers printed sensor tags, OpenSense™, in this area.
- Higher resolution patterning processes. In addition to the constant pursuit to continuously accommodate more functionality in less space, there is an immaturity of equipment for printed electronics. Equipment was originally developed for the graphic industry and when used to produce electronics requirements concerning resolution and homogeneous layers are much higher. There is a need for improvements in printed resolution as well as inline inspection and real-time feedback systems.
- **Antenna, microwave and terahertz systems**
  - Higher transmission data rates and increasing data traffic
  - Increasing operating frequency, 60, 77, 90, 120 and 300 GHz research on THz operating frequencies
  - 5G
  - High reliability
  - Saving energy
- **Sensors**
  - Automation and continuous monitoring of processes go hand in hand in the endeavour for more competitive manufacturing. This requires sensors for parameters such as light, radiation, pressure, flow, level, temperature and acceleration
- to be integrated with electronics and communicating systems.
- Sensors integrated in products provide the owner (or manufacturer) with real-time data about product status, opening up for new business models, going from selling products to selling performance or outcome.
- Wearables has started in the wellness and self-quantification area but is expected to expand into distribute health care to meet the challenges of providing health care to an increasing and ageing population.
- Autonomous vehicles.
- Robotics and artificial intelligence.
- Self-sustained regarding, for example, energy.

#### 4.7.2 Goals & Visions

##### • Printed Electronics

- Standardisation and consistent characterisation of devices
- High throughput in line quality control

##### • Antenna, microwave and terahertz systems

- 5G network at 10 Gb/s
- Very wide bandwidths (e.g. hundreds of MHz to several GHz) to be provided at overall system capacity 1000 times state-of-the-art (end 2014).
- A network that does not break, exceptionally high reliability

##### • Sensors

- Everything sensibly connected
- Robustness

## 5. A selection of prioritised ideal concepts

In the previous sections, high-level goals and global trends were identified and discussed. Together with the current state-of-the-art, a gap analysis can be made resulting in identified “white areas” that require further development. In this roadmap, we have chosen to express white areas as ideal concepts. An ideal concept is characterised by the following:

- A vision statement.
- Inspired by specific industrial trend(s).
- A demonstrator of how technology and methods can respond to needs.
- Reachable by 2030.
- An inspiration to new RD&I projects.

The following ideal concepts have been developed:

- Optimised production with high degree of automation
- Right competences short and long term
- Efficient value chains
- Availability of test, pilot and verification labs
- Streamlined development and production processes
- Technology uptake

Figure 5 shows how each of the nine ideal concepts contribute to research and development areas defined in chapter 4.

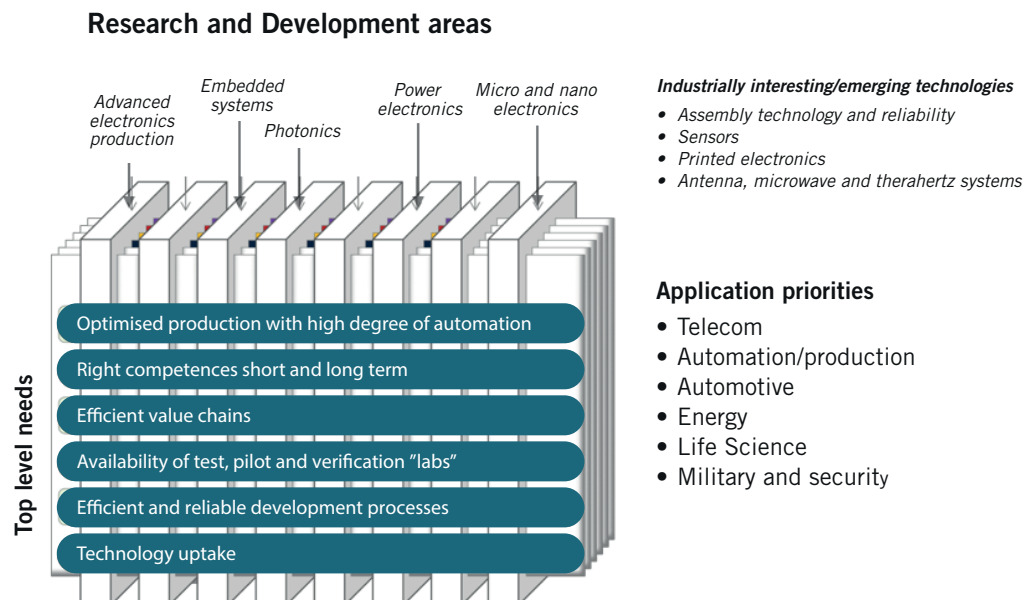


Figure 5: Impact of research and development areas to fill the gaps identified in the ideal concepts.

## 5.1 Optimised production with high degree of automation

### 5.1.1 Vision

Reduced time to market obtained through streamlined development and production process with a strong digital integration with necessary stakeholders, systems and devices. Underpinned by electronics production capabilities with high degree of flexible automation enabling cost-effective volume production of highly customisable advanced electronics. Leading to reduced time to market and efficient production ramp-up.

### 5.1.2 Description of Ideal Concept

The digitisation of production calls for digital interaction along the:

- Supply chain
- Production chain and
- Product life cycle

Such digital interaction will enable appropriate information about:

- Customer customisation orders
- Component supply situation
- Production line status and capacity
- Maintenance forecasts and related production interruption

This integration and a closer integration to electronics production and the associated automation. Electronics production of today already has a certain degree of automation aiming to optimise throughput, yield and quality. Ideally,

the production process should be able to automatically handle customisation of each product based on order even for large volume products like consumer devices. Such production might be distributed where for example the final customisation is made in the shop in interaction with a salesperson or a sales machine.

### 5.1.3 Trends Supported by the Ideal Concept

Market changes towards higher degree of customisation calls for the next level of production flexibility enabling individual customisation of the product. An example is sales of running shoes from Adidas, where already today production takes place in the same city as the shop. The next step is that shoes will be produced in a 3D printing machine in the shop. Even mid-range running shoes will have embedded electronics supporting different types of measurements that will produce data to be transferred to the customer's smartphone, smartwatch, tablet or laptop. This will call for at least software configurations or download at purchase time. It might even call for hardware configurations at purchase time.

For professional and industrial devices, capabilities to customise devices to specifications (hardware and software) will support cost reduction but probably most importantly reduced engineering and deployment costs for the customer.

#### **5.1.4 Visions and Long-Range Goals supported by the Ideal Concept**

The long-range goals and visions supported by this ideal concept are connected to the increased agility of devices and systems to surrounding stakeholders, systems and devices. This indicates that the present combined production capability relies on the current capabilities of a number of stakeholders, systems and devices.

#### **5.1.5 State-of-the-art Analysis**

Today's electronics production is to a large degree characterised by volume production of identical electronics with some customisation through software configuration mainly performed by the end user. In electronics packaging we also find some customisation but mainly for consumer devices like cell phones.

#### **5.1.6 Proposed Actions**

- Move to digitised production platforms with a clear transparency from ERP to

MES to SCADA/DCS to sensors and actuators

- Enable product software configuration based on customer specifications
- Enable a strong digital integration along the production value chain
- Enable a strong digital integration along the life cycle value chain
- Substantially reduce engineering cost design time and runtime engineering of the production system
- Make produced product quality assurance an integral part of the production process
- Enable integrated distributed production chains supporting late customer customisation

#### **5.1.7 Business Potential**

The following improved business potential is identified:

- Production can move into end user engineering, deployment and operation process
- Production will support late customisation, thus facilitating smooth buying decisions

## **5.2 Right competences short and long term**

#### **5.2.1 Vision**

The availability of people with the right training and interest in smart electronic systems is assured at all educational levels. Recruitment problems should not prevent the area growing in international competition.

#### **5.2.2 Description of Ideal Concept**

Electronics Engineers trained in Sweden have an overview covering both the design and the production of electronics. All electronics are designed to be manufactured at optimum cost and with

high reliability. Additionally, electronics engineers are used to working in teams to take advantage of all aspects of the end-use of the product in its right environment.

Sweden is self-sufficient in training engineers (electrical, software, physics, etc) for design and manufacture of world leading electronics. Increasing the proportion of women applying for upper secondary technical and scientific programmes, without losing male applicants, is a fast track to increase the number of potential engineers. Ability of electronic systems to solve future societal challenges will make the electronics sector an attractive workplace for both men and women. With a gender balance and representation of all ethnic groups in the industry, we ensure that as many aspects as possible are taken into account in the design and manufacture of future electronics.

Sweden continues to conduct world-leading research in selected electronics related cutting-edge areas. By means of exchange programmes, graduate schools and collaborative projects between industry and academia, we ensure that the Swedish electronics industry has access to research results of absolute world class.

### **5.2.3 Trends Supported by the Ideal Concept**

Electronics is becoming an increasingly important part of more and more products and systems, meaning electronic engineers will be needed to develop more and more products.

That more electronics engineers are needed is confirmed by the series

of interviews conducted by Smarter Electronic Systems over the spring and summer of 2015, see Table 1.

Electronics production is becoming more automated and products are moving towards customisation. Reliability adds value, especially for premium products. To design for manufacturability is becoming increasingly important in these contexts. Bearing in mind the fact the end product will also be used in completely new applications such as distributed diagnostics and health care, autonomous vehicles and other safety-critical systems, it becomes clear that it is absolutely essential to take advantage of all aspects of the end-product use and functionality. It is often not possible for individuals to grasp the big picture, but complementary and faceted spirit abilities of the groups will be needed.

Regarding cybersecurity there is a need to increase the awareness of the problems in the industry and incorporate the subject in the education system. Cybercrime is costly for society but more important than the cost, however, is the fact that an industrial plant that has been sabotaged cannot be retrieved from a backup stored somewhere safe. Even more important than this is the fact that many industries have processes that can cause serious environmental damage and risk the lives of people who work at the site or live close by.

### **5.2.4 Visions and Long-Range Goals supported by the Ideal Concept**

Reliability of end products will be enhanced by design for manufacturing. Smart systems and the Internet of

Things mean increasingly more electronic products and the cybersecurity issue make it more relevant to have an understanding of both software and hardware design. The expected growth of photonics and the emerging technologies listed in chapter 4.7 will require more electronics engineers.

### 5.2.5 State-of-the-art Analysis

In the interviews a majority of companies chose 3, on a scale 1-10, on the question “Can you find the properly trained persons you need within electronics?”.

1=not at all, 10=yes, fully. Less than 10% chose 9 or 10. Interviewed companies were also asked about the number of employees in different categories related to electronics, present number of employees and estimated number of employees in 5 years, see Table 1. Estimation from 170 companies resulted in an expected increase of 620 employees (electronics-related employees only). 170 companies randomly chosen out of 11,000 companies extrapolates to a need for 40,000 new employees in 5 years for the electronics industry as a whole.

Employed in interviewed company	Numbers at present	Estimate in 5 years	Extrapolated need for entire industry
PhD	169	211	2,700
Industrial PhD	15	40	1,600
MSc	1,294	1,787	31,900
BSc	1,360	1,602	15,600
Technical college	987	805	-11,800

Table 1: Number of employees in different categories related to electronics, accumulated figures for 170 interviewed companies. Last column extrapolated numbers in entire industry, 170 companies out of about 11,000. Estimated numbers in 5 years are absolute and do not include those who need to be replaced due to retirement.

Looking at available education options in electronics in Sweden we find:

1. At technical college (upper secondary school) there is no dedicated programme for electronics production or electronics design. The most relevant programme is the Electricity and Energy programme, which offers 3 individual courses at 100 p each in electronics.

2. At the level above technical college, Electronics manufacturing is only available as singular courses in electronics engineering programmes. Electronics design/engineering has dedicated programmes at most universities.

The latest available statistics from the National Agency for Education show that for the school year 2014/2015 applicants for primarily science programmes and

technology programmes numbered 14,805 and 9,299 respectively. If these numbers are constant over time, 1/3 of all those who start (primarily applicants) these two programmes are needed to meet the estimated increase in the electronics industry

#### **5.2.6 Proposed Actions**

- Immediately start initiatives that increase the attractiveness of technology and science programme at upper secondary school.
- Incorporate cybersecurity in engineering education both in basic education and as short courses for personnel active in the industry.
- Form a council to provide support to the National Agency for Education in the design of courses in a practical high school programme.
- From the need-finding interviews, some special skills were highlighted as particularly difficult to recruit. Therefore, it is necessary to influence some universities to start programmes with specialisation in electronics production, reliability and analogue design.
- Influence electronics engineer/design programmes to consider design for manufacturability.
- Establish a programme that prepares employees and their companies for industrial doctorates in close collaboration with the supervising and examining academic institution.

## **5.3 Efficient value chains**

### **5.3.1 Vision**

All needed value chains for making smart electronic systems in Sweden are strong and sufficient to bring the innovation from idea to market. Efficiency in the cooperation and integration between value chains minimises time-to-market and makes the Swedish industry highly competitive. Strong value chains attract international investment to Sweden. Small companies also have access to foreign markets and investment and increase their numbers of exports. The value chains include fruitful international collaboration for research, development and production.

### **5.3.2 Description of Ideal Concept**

The disciplines within the smarter electronic systems value chains in Sweden cover all the way from concept and innovative research to a product put on the market, a journey that also constitutes the very definition of innovation.

The actors are many and diverse, with for example many small companies with different engineering specialties, but also major global players. Different actors develop, manufacture and distribute components, which in turn are built into the systems by other actors. The systems can then become part of the applications, which are developed and

manufactured by yet other players. The journey from idea to market thus takes place via the value chains of linked actors. The links in the chains must be well connected to be able to attain the final goal. This means that we need to ensure that the flow is uninterrupted and efficient. Each link in the chain must maintain competitive skills, and collaboration between the links needs to be developed and enhanced.

### **5.3.3 Trends Supported by the Ideal Concept**

Sweden has an outstanding position internationally in the application areas of telecom and automation. Other internationally strong industrial areas with high content of ICT ECS are automotive, avionics, life science, construction, mining and defence technology, all of which yield a high contribution to Swedish exports. Value chains have been identified and mapped for all these fields. Their impact on societal challenges is dependent on the value-adding strength of the individual links. In Sweden, the long-term trend has been a shift to the higher levels of the value chain. Recently we find a shift in focus towards the need for closer collaboration between different links in the value chain. Close collaboration between for example design, manufacturing and test is thus required to be innovative and competitive and to deliver reliable products since reliability and manufacturability have to be designed into the product.

- Globalisation – interconnected world.
- Electronic solutions are meeting global societal challenges; energy, healthcare, etc.
- Increasing global demand of electronics in almost every type of industry and product.
- Increased international collaboration.

### **5.3.4 Visions and Long-Range Goals supported by the Ideal Concept**

Establishment of efficient value chains for the identified industrial fields, preferable with competence in Sweden. Otherwise through a strong European collaboration. Aiming for a strong technology and supply base serving an international market network.

### **5.3.5 State-of-the-art Analysis**

In the need-finding survey, we have found that a large percentage of the companies will rate activities enhancing interaction between the actors high. We can also see a lack of knowledge and use of for example standards, which would increase efficiency and quality in the information flow. We also find competence gaps within the different links. The conclusion is that there is a significant potential to make the industry more competitive in the global market by enhancements in the value chain domain.

Being a small country, Sweden is dependent on exports and internationalisation. Sweden has a long tradition of being a successful export nation. With its major flagship companies in telecom, automation, automotive,

life science, etc., Sweden's reputation of being a competitive and qualitative trading partner is solid. Sweden is also characterised by being stable, both in the geological and political sense. In combination with high technical skills and an innovative culture, Sweden has a good platform for expanding exports and benefiting from increasing internationalisation. Stability and reliability also make Sweden an attractive country for production investments.

One major weakness can be found in the structural distribution of company size. There are many successful large enterprises and there are many small innovative companies, but there are few medium size companies. The small companies are often built around an innovative new product or process, with highly specialised personnel. They often lack both the competence and the muscle for international marketing. Acquisition by large international companies usually happen to the most successful SMEs and is also normally considered a success, although this usually prevents significant expansion in Sweden.

Our need-finding project has shown that many of the companies have a desire to increase their internationalisation and export sales. The small companies in particular need different types of support to help them enter the global market. The support needed includes networking arenas, collaboration with international partners, mentorships and export activities.

### 5.3.6 Proposed Actions

Create better knowledge transfer and interaction in value chains

- The value chains are linked to each other where some players develop components, others systems and yet others applications. The players are links in an innovation chain that constantly changes as technologies and players change. No player covers the chain by itself. Most players are small and cannot afford to have all the required knowhow in-house and therefore need arenas for development, sharing and transfer of knowledge. One currently identified gap in the value chain is within electronics production. A well-funded competence centre for advanced production engineering would be an important step towards filling the gap.
- Each chain drives activities from idea to product and it is important to ensure that this is done in an efficient way and without interruption. To increase the use of standards and facilitate communication between actors will shorten time-to-market and increase competitiveness. Actions include meeting platforms, seminars and networking.
- The final innovation leading to a complete product ultimately depends on the collaboration between the players within and between the different value chains. Knowledge transfer between the players is crucial for the functionality of the system for innovation in the ICT ECS industry. Actions include programmes for knowledge transfer (like tekniQ, minST)

and more employee exchange between academia and companies.

- Export and internationalisation actions:
  - Improve collaboration with Business Sweden and Enterprise Europe Network.
  - Organise delegation trips to chosen markets/countries.
  - Develop communication materials for marketing Swedish companies in selected areas.
  - Extend the scope of the Advocacy platform beyond H2020 and ECSEL.
  - Provide arenas for companies to find partners for joint export efforts, especially interesting to strengthen the SMEs through collaboration with (large) companies in Sweden who are already established in the international market.

### **5.3.7 Business Potential**

Efficient value chains are crucial for the product to reach the market within the market window. With the development time for a new product constantly becoming shorter, it is necessary to make the value chain work optimally. Time-to-market is one of the most important parameters for the competitiveness and success of a new product. The business potential of an increase in exports is fairly obvious. The electronics industry provides improvements for other industries to use, both in their products and their production. Electronics thus both strengthens international competitiveness in other Swedish industries and is an export industry in itself, as the demand for electronics is global in a wide range of application areas.

## **5.4 Availability of test, pilot and verification labs**

During the interviews several companies indicated the need for test facilities. Some comments were of a more general nature, while others targeted specific needs. EMC test was one of the specific facilities needed. It should be understood that the need does not refer to accredited test sites, which are well known, but labs where companies can test their designs early and tweak them to fulfil the requirements. Pilot lines for production were also mentioned.

### **5.4.1 Vision**

When new packages, new components and new materials enter the electronics industry there should be an infrastructure of test sites and verification labs to evaluate them for a given working environment in order to achieve high quality and high reliability in the end product.

#### **5.4.2 Description of Ideal Concept**

Ideally, an OEM should be aware of the actual working environment of their end products and should understand the requirements set by regulations such as the CE-mark in Europe. Based on this knowledge there should be test sites where companies can verify their products either using their own personnel or purchasing a defined test based on standards or similar documents.

The test and verification labs should (at least) include:

- Temperature cycling facilities
- Humidity tests
- EMC-labs
- Parts of LVD testing
- Highly accelerated life testing and highly accelerated stress screening
- Automation test lab
- The pilot lines should for example include:
  - Pick and place and soldering lines
  - Cleaning facilities
  - Conformal coating facilities
  - Application of underfill

When the test facilities are available the OEMs can perform reliability tests based on the principles of “Physics of Failure” that would be a major cornerstone in attaining high-quality products.

#### **5.4.3 Trends Supported by the Ideal Concept**

The interesting part is that many facilities do exist in one form or another under different economic constraints but this seems to be largely unknown.

Research institutes and private companies already have, for instance, EMC-labs available for companies.

There are also projects and networks in other areas like Fiber Optic Valley AB in Hudiksvall for optics-related research and testing and MyFab for nano electronics to mention just a few. Another example is Adopticum in Skellefteå that addresses vibration, shock and temperature tests.

#### **5.4.4 Visions and Long-Range Goals supported by the Ideal Concept**

The long-range goal and visions supported by this ideal concept are connected to the increased interest on the part of the industry to provide products with high reliability in harsh environments.

#### **5.4.5 State-of-the-art Analysis**

There seems to be an information gap between producers (those who have test sites) and buyers (companies in need of test sites) that needs to be addressed. If producers learn more about the buyer’s actual needs, more test sites, not currently being marketed, could be used. One obstacle might also be the mix of commercial constraints for different sites where membership is often required.

In addition, the standards and tests used are in many cases not relevant for assuring acceptable reliability. Many of the standards are based on “best practice”, i.e. experience of mature technologies: the requirements may therefore not be relevant or sufficient

for products manufactured using new technologies.

There is also an understanding that meeting requirements in standards alone can guarantee good quality and good reliability. The real situation, however, is different. There is a general misunderstanding of the concept of “quality” and the concept of “reliability”.

In the standards and handbooks the situation is clear. In, for instance, IPC J-STD-012, Implementation of Flip Chip and Chip Scale Technology:

- “Meeting criteria in J-STD-001 and IPC-A-610 does not assure reliable solder connections, only quality solder connections.”

Similar fundamental comments can be found in textbooks:

- The Electronic Packaging Handbook  
“For our purposes, a quality product will be defined as one that meets its specifications during the manufacturing and testing phases prior to shipment. This is different from reliability, which can be defined as a product meeting its specifications during its expected lifetime.”
- The Communications Facility Design Handbook  
“The focal points of any quality assurance effort are quality and reliability. These terms are not synonymous. They are related, but they do not provide the same measure of a product.
  - Quality is the measure of a product’s performance relative to some established criteria.
  - Reliability is the manner of a product’s life expectancy.

#### **5.4.6 Proposed Actions**

A relatively straightforward approach to resolve these problems would be to scan the market for test sites and present these on a website. Sites run by research organisations or where research organisations are members would be easy to find. Those run by companies requires some more effort. The site should list all requirements like membership, yearly fees, etc. in an easy to understand way and, if possible, also hourly rates if this applies. It should be mentioned that efforts in this direction have already been made by commercial magazines and organisations. A first step would be to try to understand why these have failed. A second action is to educate OEMs on the difference between performing standard tests and testing based on the concept of “Physics of Failure”.

#### **5.4.7 Business Potential**

The industry in Sweden mainly produces electronic devices or sub-assemblies for products with a relatively high expected lifetime, ten years or more. There is a market for suppliers of electronics hardware that meet long expected life times in harsh environments globally. This niche could be a Swedish specialty in a global market.

## 5.5 Technology uptake

### 5.5.1 Vision

Swedish electronic systems are well visible and used in Sweden and abroad among technology partners and throughout the main end-user communities.

### 5.5.2 Description of the Ideal Concept

Technology uptake addresses the efficiency in industrialising products based on new technology and/or their use in new markets. It follows a process of dissemination, discovery and implementation of technologies in new application areas and/or in combination with other technology areas or new partners, enabling new products and new markets. Efficient technology uptake therefore implies efficient communication and interaction with many different players. Communication can occur at many different levels, from education in high school with a long-term perspective to workshops on a particular focus with well-chosen protagonists and for short-term results, via all sorts of media such as videos, fairs, reports and articles in the specialised and general press. Discovery and implementation are more difficult to control but will also have to be addressed. For new companies, technology uptake is one of the keys allowing a successful journey through the so-called valley of death. The other keys are described elsewhere in this chapter and deal with efficient value chains, availability of pilot lines

and lab infrastructures, availability of competence and successful and efficient productification.

### 5.5.3 Trends Supported by the Ideal Concept

- Hyper-specialisation of all technological sectors hinders proper overview and exchanges.
- Major innovations require the involvement of many competences and technological solutions.
- Innovations that consider sufficiently many aspects of a problem are more likely to be successful.
- Interaction between technology and market niches provides new opportunities in markets with similar requirements

### 5.5.4 Visions and Long-Range Goals supported by the Ideal Concept

- Devices and systems for Smart Sensors and Systems Integration to meet global challenges and develop systems for Smart Energy and Smart Cities.
- Better simulation and analysis methods open up for more reliable electronic products in new environments (thermally, mechanically etc).
- Viable platforms for cooperation between photonics and medical professionals.
- Photonics solutions enabling highly efficient and flexible production with integrated quality assessment.

- Intelligent Human Centric Lighting solutions combined with IoT for multiple purposes: communication, health and energy efficiency.
- High-performance near- and mid-infrared (NMIR) equipment for imaging and sensing applications brought to the consumer market through reduced cost, size and user complexity.

### 5.5.5 State-of-the-art Analysis

The efficiency of technology uptake is an important focus of organisations representing enabling technologies. A very large proportion of the new technologies are developed by SMEs, i.e. by definition organisations with limited resources to investigate new markets and attract new customers. Leaving the technology silos and getting into close contact with end user industry or other technologies is probably the most complex thing to master and also difficult to monitor. Nevertheless, it has to be done for certain companies/technologies to survive. In Sweden, an example of action to stimulate technology uptake is Vinnova's programme presently called "Innovationsprojekt i Företag".

In Sweden and other European countries, strategic measures are being taken to foster technology uptake. The German push on Industri 4.0 and digitisation is one example. At the European level, there are several initiatives trying to tackle the issue:

- The H2020 programme has an emphasis on technology uptake and shortening time to market.
- The ECSEL-JU and the Photonics21 PPP engage with the "Societal

Challenges" - end user – part of H2020 to trigger awareness of electronic systems and gain influence on the calls.

- Within H2020, there is a specific focus on SME technology uptake.
- Dedicated H2020 projects have the task of providing prototyping services to SMEs targeting a product with market opportunities. An example is the EuroCPS project.

### 5.5.6 Proposed Actions

- Creation of a portal to Swedish Electronic Systems. The portal will allow Swedish technologies, products and companies to be detected in the areas covered by ECS. The portal will also show the impact of ECS technologies on the different application areas as well as the links and collaboration of ECS with other organisations. Need owners will be able to post a description of what they are looking for.
- Study and integration of selected technology uptake actions of other Swedish and foreign organisations.
- Organisation of large end-user workshops with match-making opportunities and starting points for formalised collaborations. Example: in the health sector, together with two other strategic innovation programmes Medtech4Health and SWELife.
- Programmes to increase the mobility of personnel between different competence areas within ECS and between ECS and other technological or application areas.

### 5.5.7 Business Potential

Technology uptake will occur both within ECS and between ECS and other technological and societal fields. It will

significantly accelerate innovations in many fields and the economic growth of electronic system based companies in Sweden.

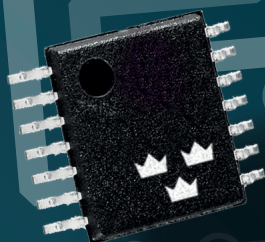
## 6. Main sources of information

We would like to thank the following people for valuable contributions to the content of this roadmap:

- Michael Salter, Acreo
- Mikael Östling, KTH
- Mietek Bakowski, Acreo
- Hans-Peter Nee, KTH

## References

- [1] "Smarter electronics systems for sweden," Acreo, Tech. Rep., 2014. [Online]. Available: <http://www.smartareelektroniksystem.se/uploads/5/0/4/8/5048434/smarter-electronic-system-for-sweden-english-version.pdf>
- [2] J. Gustafsson and M. Svensson, Behovsanalys smartare elektroniksystem för sverige.
- [3] M. Naumanen, "Roadmap – kartta menestykseen," Met-julkaisuja, no. 23, 2001.
- [4] V. Kamtsiou, A. Naeve, L. Stergioulas, and T. Koskinen, "Roadmapping as a knowledge creation process: The prolearn roadmap," Journal of Universal Knowledge Management, vol. 13, no. 3, pp. 163–173, 2007.
- [5] O. Ventä, "Älykkäät palvelut – teknologiatiekartta [intelligent systems and services – roadmap]," VTT, Espo, Finland, Tech. Rep. Reseach notes 2243, 2004.
- [6] A. Meyer, "Photonics in europe, economic impact," Optech Consulting, Tech. Rep., 2009.
- [7] "Preparing for our future: Developing a common strategy for key enabling technologies in the eu," European Comission, Tech. Rep., 2009.
- [8] "High level group on key enabling technologies," European Comission, Tech. Rep., 2011.
- [9] "Photonics strategic research and innovation agenda, photonics a key enabling technology for sweden," Photonics Sweden, Tech. Rep., 2013.
- [10] "Strategic research agenda," ECPE – European Center of Power Electronics, Tech. Rep., 2011.
- [11] "A european strategy for micro- and nanoelectronic components and systems," Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Tech. Rep. COM (2013) 298 final, 2013.



## **Smartare Elektroniksystem för Sverige**

[www.smartareelektroniksystem.se](http://www.smartareelektroniksystem.se)

Med stöd från:



**STRATEGISKA  
INNOVATIONS-  
PROGRAM**