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Integrated miniaturised systems 2020 and beyond

Final report
Integrated miniaturised systems for 2020 and beyond

Final report

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Executive Summary

This chapter summarises the result of our study on integrated miniaturised systems.

The study objective and scope

It was the objective of the study to:

- Identify the major technological and scientific challenges and drivers to realise integrated miniaturised electronic enabled systems with whatever high technology (electronics, micro-systems, embedded software, embedded systems) that serve the purpose, with a system view approach and with a view for their implementation in applications in 2020 and beyond;

- Identify and describe the strategies and business developments trends for the EU-industry in order to stay at the forefront in developing electronic enabled advanced products;

- Identify and describe key application domains where Europe is strong and which could greatly benefit from a largely improved capability to produce advanced nano-electronics systems. The potential impact for the industry and society must be taken into consideration.

The whole study has taken stock of the advanced research done already up until today and the long term needs for the related high technologies. The study aimed at identifying the relationship between these needs and actions to be started in the near future. Furthermore the study describes the change in the R&D models in the area of nano-electronics and identifies the European specificities and needs.

To make the study feasible, in consultation with DG INFSO and based on the existing pool of knowledge in the team and in the literature, the consortium decided to choose from the list of Grand Challenges (GC) those where integrated miniaturised systems have a positive contribution for technological development and innovation.

These grand challenges have a strong impact on various layers of applications. Accordingly, we have looked at application domains and applications that are initiated by these four selected grand challenges. An example of an application domain is: ‘smart infrastructures’ aiming at optimising the traffic flow. Potential applications might be, e.g., route decision systems depending on the amount of traffic; intelligent traffic light control to optimise traffic flow; changing street toll to optimise the amount of cars on the street. Alongside the application a number of technological devices (e.g. sensors/actors) and business model innovations (e.g. smart street tolling systems) are needed to
transform need into demand. It will require new actors on the market (toll companies, suppliers of smart products to enhance the infrastructure, satellite providers etc.).

Traditional technologies like the centralised traffic flow control will be substituted by decentralised at least partly autonomous, but interactive new systems. The economic trends and drivers to identify and describe the strategies and business development trends in selected application domains with a strong need of integrated miniaturised systems are tackled in this study from within the electronics sector (what are the main strategies of the electronic industries in Europe and globally) and from the applications and market that have a strong pull on the electronics sector (e.g. the automotive industry).

Finally, the identification of major technological and scientific challenges and drivers is tackled from within the nano-electronics based integrated miniaturised systems (e.g. challenges related to miniaturisation, IC-design, energy resourcing) as well as from external drivers as for instance a demand for smaller and smarter systems from various application domains.

Thus the study combines four perspectives to identify paradigmatic changes in applications and technologies: societal, technology & research, economic & industry, as well as policy. In our methodology we have combined the four dimensions by identifying the joint junctions between technology, grand challenges and applications to generate a vision of future usages of integrated miniaturised systems based on existing paradigms, as well as on paradigm shifts identified by the actors in the field. Based on that information we have developed policy recommendations for the European Commission to identify strategies to overcome barriers that prevent European players from gaining a leading edge in the most promising fields of integrated miniaturised systems.

We have attempted to collect visionary ideas connected to the Grand Challenges and linked these to the broader application domains that were selected. Visionary ideas are however mostly defined on a high level of abstraction. Those visionary ideas that could be easily translated into specific application domains or even more specific applications are not readily ‘out there’ to grasp. Our empirical research confirmed the idea that any visionary company or research organisation with such ideas would have an interest to exploit these immediately and most likely not disclose what this potential ‘killer application’ would look like. On the basis of desk study, surveys and interviews it cannot be expected that a study of this nature (many different levels of abstractions) will be able to detect the next generation of ‘killer applications’.

We have however selected an approach that tries to bundle grand societal challenges with application industries and technologies to identify what technologies and industrial configurations are needed to realise future answers
to the demands defined by the grand societal challenges discussed in this study and feed into the decision-making of the European Commission for the future.

**Societal challenges and drivers to realise integrated miniaturised systems**

The empirical work showed that integrated miniaturised systems contribute to solve demands initiated by grand societal challenges. The societal challenges form an impetus for the demand for new products and services of IMS, either driven by consumer and intermediary demand on the market and/or answering to public policies that deal with societal problems. The literature review showed that two mechanisms underpin the guiding effect of the grand societal challenges as basis for research and development: societal responsibility and potential valorisation or commercialisation opportunities.

This study elaborates on 4 grand challenges: health and ageing, climate change, sustainable production as well as sustainable mobility. These grand challenges have a guiding effect on R&D activities in the domain of IMS at the level of companies and research institutes. In turn, IMS offers promising applications that deal with societal challenges, which are specified below.

- **Health and Ageing** deals with the ageing populations and associated challenges to the health system. Entrance points for applications of IMS are quick and easy (integrated) diagnostics tools; applications for minimal invasive therapy; and assisted living of elderly and patients.
- **Climate change** puts limitations to our demand pattern, especially of our energy production and use. Promising applications of IMS include: renewable energies, notably solar and wind power; and smart grids including smart metering.
- **Sustainable production** deals with optimising the efficiency of production processes, or development of new production methods with higher efficiency with regard to energy and (scarce) material use. Interesting applications of IMS contribute to higher supply chain and logistics efficiency in production processes, as well as flexible and adaptive production processes, intelligent machinery and zero-defect production.
- **Sustainable mobility** deals with all aspects of mobility that currently impact our environment, our living conditions as well as the economy. Important solutions IMS offer are applications for advanced driver assisting systems and new or improved propulsion systems.

**Key application domains where Europe is strong**

The number of potential applications that could benefit from IMS is virtually unlimited. The earlier mentioned applications show a clear and balanced link with the grand challenges. In order to arrive at a final and meaningful selection of promising key application domains and applications, an analysis
and review of existing and future trends and developments in each of the application domains is made, based on existing studies and other relevant material (e.g. ETP roadmaps, company annual reports), taking account of technological, economic and other factors. Furthermore, an inventory is made of how the broader IMS-stakeholder community perceives and valuates the current and future opportunities and challenges in each of the application domains. Both interviews and an online survey among a sizeable sample (see Appendix B) of stakeholders were used to map and assess the opportunities and challenges.

Health and ageing

The expenditure on medical devices is sizeable; yet still a small part of total healthcare expenditure worldwide. The demand for medical devices is, however, rising fast. Reasons for growth of the health and ageing market are related to longer life expectancy, more attention for health in general, but also to increased harmonisation of standards and norms in the healthcare market. Another major trend affecting the future of health care is further convergence in technologies, such as the sharing of medical information between medical devices and IT applications and networks. Both the trend of miniaturization and of convergence are well reflected in the increase in demand for monitoring devices, both for personal and for professional use. In order to be used in the best possible way, medical devices should be flexible and take the local context in which these are used into account (WHO 2010). The US, Europe and Japan are the main producers of high-tech medical devices. The main companies in Europe are Siemens, Covidien, Philips, B. Braun, Cardinal Health, Smith & Nephew, Alcon, Fresenius Medical Care and Dräger. These companies are located in Germany, the Netherlands, Ireland, the UK and Switzerland. European companies spend with 8% of their sales revenue more than average on R&D. European companies account for 12% of total patent filings, which is more than any other industrial sector in Europe (Eucomed 2010).

Sustainable mobility

Both ITS systems, ETC systems and real time multi modal transportation information systems can be beneficial for reducing congestion, one of the main issues in transport. With around 300 million drivers in the EU today, and further expected increases in the distance travelled by road, it is expected that congestion costs will increase further by about 50% up to 2050 (CEC 2008). Intelligent transport systems, or, advanced driver assistance systems, also provide opportunities for increasing safety. Finally, hybrid electric vehicles and Electric vehicles (EVs) provide major opportunities for emission reductions and economic growth.

European companies in the automotive sector spent more than twice the average manufacturing share of their value added on R&D. This share grew from 13% to almost 15% in the period 2000 to 2007. Although the industry is dominated by large OEM’s, about 50% of R&D investment comes from
automotive suppliers. This also holds for the majority of patents. In terms of competitive position, European OEM’s and systems and component providers have a leading position in ADAS systems worldwide. Major European systems and component providers are Bosch, Alpine, Siemens, Mannesmann, and Continental/VDO. European automotive firms are leaders in some transitional drive-train and fuel technologies and are investing in ground-breaking technologies, such as battery-powered hybrid vehicles, electric vehicles and hydrogen. As products are becoming increasingly complex from a technological point of view (e.g. the role of electronics), the industry is focusing increasingly on advanced, high technology products, which necessarily rely on a highly skilled workforce.

Sustainable production

Energy and resource efficiency are two important societal challenges. As prices for raw materials and energy are expected to rise, both resource and energy-efficiency are vital for EU manufacturing. The use of metering and control devices can however still improve energy-efficiency by 30%. The potential appears, however, biggest in the building or transport sectors, where energy intensity has increased. There is also a great market potential for recycling techniques. Recycling can be importantly increased by smart sensor sorting and advanced density separation and recovery techniques. Finally, workplace safety is another part of the sustainable production challenge.

The mechanical machinery and equipment sector is the largest with a share in total manufacturing value added of 11.6%, whereas the electrical machinery and equipment sector is responsible for 4.7% of manufacturing value added. The sector contributes highly to European value added and as producer of so called key enabling technologies, is an important source of competitiveness for the European industry. In 2010 the EU was the leading worldwide exporter of machinery and equipment and provided 37% of world exports of machinery and equipment (NACE 29). EU producers are less important in the electrical equipment part of export markets. The EU and Japan are however leading in high tech machinery. The main competitors of the EU are the US and Japan and to a lesser extent Taiwan and Korea. Expenditure on R&D in the EU is similar to the expenditure on R&D in the US and Japan, while in 1999 Europe was lagging behind, especially compared to Japan. In general, the strength of the European M&E sector lies in combining and integrating new advanced technologies, such as lasers, gear and drive technologies, sensors and optoelectronics, new materials with more “traditional” mechanical engineering technologies (Ecorys 2011). Moreover, the ability to automate and control complex processes have made EU manufacturers highly demanded suppliers of complex and high tech machinery and equipment. The EU is on the leading edge globally, next to Japanese firms and to a lesser extent US firms (Ecorys 2011).

Climate change and energy
Climate change offers opportunities for new technologies including emission abatement and clean(er) energy. Wind energy for example, is the second-largest contributor to renewable electricity today after hydro energy. The EU also has several large solar energy companies, most notably in Germany. The importance of solar energy as an alternative sustainable energy source has increased over the years and with improvements in photovoltaic technology, costs are expected to decrease and solar power will become more and more attractive. The increased use of renewable sources requires however greater power system flexibility than is the case with most conventional sources. This can be achieved by smart grid and energy storage technologies.

For many appliances production and development has shifted to Asian countries, which is especially the case for radio, computer and television equipment. European companies still have a competitive position in washing and drying machines. Bosch, Miele and AEG are examples in this case. Therefore it is questionable to what extent European companies are able to profit from developments in smart appliances. Companies that produce products related to climate change fall mainly under the machinery and equipment sector, which has already been discussed. There, it was discussed that for energy efficiency, European companies have a competitive advantage compared to other regions.

Based on empirical inquiries the study was able to show that in particular the following application domains have a strong impact by integrated miniaturised systems:

- Applications that enable smart metering, control and sensing in combination with smart grids (Climate Change)
- Miniaturised self-monitoring for personal use and miniaturised diagnostics or monitoring devices for professional use (Healthy Ageing)
- Advanced driver assistant systems in combination with real-time multi-modal transport information systems for individual users to optimise transport mode and route selection. (Sustainable Mobility).

These application domains show a high ability to contribute to the solution of problems initiated by the grand societal challenges. They also show high economic potential for European players. The competitive position of European players acting in these application domains is fairly strong as is the systemic complexity of technological and economic approach.

The empirical study clearly indicated that all three application domains are challenged by high demands on applied research and the developments of

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1 In our definition also electronic equipment and components are included
demonstration and pilot installations. That makes quite sure that the majority of the experts consulted do not see a need for fundamental research results but are more concerned on those research results that reduce time to market and enhance the usability of the applications generated in the application domains.

It is, therefore, hardly surprising that experts perceive inadequate business models and economic risks as major barriers to the successful placement of applications on the market. Furthermore the lack of private as well as public research funding is tagged as a barrier.

**Main strategies and business development trends in the IMS industry**

The importance of the micro- and nano-electronics industry for Europe is undisputed and the market potential high. According to SEMI (2011) the microelectronics and software industries together nowadays “spearhead 90% of innovations on growth markets like healthcare, energy and the automotive industry”. In 2010, Europe was the third largest semiconductor producer worldwide, with 10% of total global output, 14% of total global sales and 20% of the global design activities market. Until the early 2000’s, Europe still had three of the top-ten semiconductor manufacturers in the world (i.e. STMicroelectronics, Siemens and Philips) (ICT Man, 2011).

During the 2000’s, fabless companies and foundries strongly gained importance. Over the last decade, numerous European producers either transferred manufacturing operations to Asia or moved toward an asset-lite or fab-lite model. Another parallel but related development was to spin-off semiconductor operations of large European OEMs in the early 2000’s. Both Infineon (spin-off of Siemens, 1999) and NXP (spin-off of Philips, 2006) are successful examples of this strategy. Europe witnessed a general decrease in its manufacturing capacity in semiconductors in the 2000’s. Europe has been able to maintain strengths in a number of key applications, with leadership in radio-frequency (RF), analogue/mixed signal and More than Moore technologies. An important future challenge, however, is to maintain its built-up advanced manufacturing capabilities.

There exists a direct relation between future market growth potential for IMS-based applications in Europe and the presence of strong European companies in upstream sectors. Europe’s leading position in these domains appears primarily to be related to the presence of strong existing ecosystems, in which OEMs, innovative SMEs and public research organisations are still able to develop innovative solutions. Proximity to and interaction with client industries is a crucial factor for success in these eco-systems. Whether current Europe’s competitive advantage in these areas can be maintained and expanded in the long term depends to an important extent on whether these eco-systems can be maintained and made even stronger.
European industry is facing strong cost competition from Asia and in particular China. Only leading edge and innovative products with a high degree of complexity might be able to witheld the impact of fierce international competition. Companies producing for high-end high value niche markets rather than global mass markets are subsequently more likely to survive.

**Competencies and technologies needed to realise the future miniaturised systems**

For the three selected application domains we have analysed which portfolio of technologies for manufacturing IMS is available at all, and how actors in the field estimate their competitive position in a global context. Our empirical study on technological development was driven by the hypothesis that there might be an opportunity for a paradigm shift in integrated miniaturised systems. A paradigm shift takes place if actors change their definition of problems and their problem solving activities as well as strategies.

The hypothesis of a paradigm accordingly assumes that

1. A technological mainstream for the production of IMS exists
2. Efficient alternatives exist, at least in the R & D environment, which will be supplied from an existing technology portfolio
3. An incipient penetration of these alternatives already can be detected in the community

A change from CMOS to beyond CMOS can be assumed as an example for a possible paradigm shift that also goes along with a new structure of the value chain accompanied by a reshuffling of the positions of global actors in the market. A paradigm shift therefore is a highly demanding change from the point of innovation and technology policy. It makes a change in the objectives of policy measures, the definition of impact indicators as well as the composition of actors integrated in such measures necessary.

Although the picture is not completely consistent for all technological variables, we can draw some general conclusions from our empirical work on technological developments in integrated miniaturised system.

*Technological developments*

From the survey and the interviews we can derive that the majority of the sample respondents see even in the future high potentials of the current paradigm based on down-scaling on CMOS pathway. That is true even so the empirical study on technological challenges and drivers shows that many experts are quite aware of likely limits of the More Moore approach in integrated miniaturised systems. In particular down scaling is seen as a major challenge. Based on that problem in miniaturisation, however, there is no
consensus among the experts that nano-electronics and accordingly a further consequent miniaturisation trend will be the path to solve these challenges. On the one hand actors in the field still strongly believe in the potentials of the current paradigm; on the other hand they fear that the solving power of the paradigm is decreasing. That is the reason why there are so many approaches in R&D looking for alternatives.

We rather see as the overall result from the study and especially from the questionnaire that actors mainly think within the established paradigm. A radical move towards an application-approach of e.g. new materials, new nano-electronic based devices, design and/or architecture could not be identified from the results of this study for any of the three application domains. That at least indicates that the majority of the respondents from firms are investing mainly in the developments going along with the current paradigm. This is certainly due to the fact that for the requested study period for 2015 + and the given premise of the necessary connection of the technologies used in selected applications only such technologies enter into commercial use (and because of the time-to-market can be), whose handling is known and familiar by the companies.

That result is also confirmed by the fact that the majority of the questionnaire respondents see a high potential for technological developments in multilevel developments and more important in smart software\(^2\). Instead relying on hardware developments in integrated miniaturised systems obviously several actors perceive higher returns from changing the software used in the integrated miniaturised systems.

Even so the majority of the respondents show faith in the existing paradigm a noticeable number of respondents of the questionnaire believe that the current silicon based paradigm is showing limitations. We could identify two directions in their search process for alternatives. Some see high potentials in new materials in particular if there is a shift in the paradigm towards a nano-electronics based More Moore approach. Alternatively other actors see high potentials in a move towards new architectures and designs.

Furthermore the results of this study indicate a strong importance for connectivity, preferably with radio frequency transmission solutions and for energy storage, harvesting and management as key knowledge for today’s and even more future integrated miniaturised systems. Issues like energy storage and supply as well as the connectivity with other integrated miniaturised systems are important R&D challenges many actors work on.

\(^2\) Smart Software means Efficiency, Modularity, Fault-Tolerance, Intrinsically Safety, Re-Usability, Ease to use
Competitive technological position of Europe: drivers and barriers to be solved

Looking at the competitive position of European players in integrated miniaturised systems it is to state from the study that Europe is quite good positioned in many application domains. The technological position of Europe is however a bit different.

In technologies for integrated miniaturised systems Europe is less strong than in applications. It also is more heterogeneous depending on the region we are looking at. In particular compared to the US European players are less well equipped than their US counterparts. In particular in power supply/interfaces technologies and process technologies the US is in a strong lead. That is also true for software / architectures, although the lead here is smaller. In comparison to Japan European players still are seen as strong in design/devices, process technologies and software. In comparison to the rest of Asia Europe is still in lead in most technologies inquired. However looking at the future the picture is changing. The rest of Asia is catching up in high speed. Additionally the experts assume that Europe is losing ground compared to Japan. Just in comparison to the US experts expect Europe catching up in process technologies.

Looking at today’s technological barriers and drivers to integrate miniaturised systems a bundle of drivers have been identified by the experts. Most experts still believe in a certain technological determinism. Discoveries in materials in particular show the potential to lead to new developments in integrated miniaturised systems. Most experts see European actors fairly strong in material science. For technological barriers and drivers experts perceive still strong opportunities in material sciences, followed by packaging technologies, which is at least partly related to each other.

In the view of experts in particular main barriers are generated by a lack in the existing knowledge base in Europe, the human resources available and lacks in equipment. Further barriers identified by the experts result from necessary enhancements in reliability and standardisation are needed to strengthen Europe’s position in a global context.

For the future several experts believe that Europe will be only remain competitive if the complete value chain is prevalent in Europe. With pieces in the value chain missing in Europe the experts fear that the new technological developments will not be turned into business, at least not in Europe. Experts demand for a changing future research structure in Europe. Cross linkage among industries, stronger and as more application-focused collaboration among research institutes and companies as well as (new) business models that help to reduce time to market span are main proposals by some experts.

That picture is also enhanced by the fact that several respondents see the value of new approaches in the technology variables as mainly restricted to
specialized solutions, which can serve for niche market applications. Hardly any of the respondents gave an indication of a new paradigm on the hardware sight that lead to a mass market. This result is in particular of interest for the question how much of the value chain in integrated miniaturised systems shall be present in Europe. Some actors in particular from the equipment industry have mentioned that they do not see a need for hosting the complete value chain in Europe whilst others have main concerns with the white spots in the European value chain in integrated miniaturised systems.

**Recommendations from the study**

The study has been commissioned by DG INFSO to help the Commission to develop Horizon2020 and in general its support to IMS beyond 2015.

1. Our study suggests that the European Commission should maintain a considerable share of its research and support for evolutionary innovations in the More Moore paradigm. Innovations in that paradigm will generate wealth within the next decade.

2. If STI policy wants to enhance the likelihood for a paradigm shift towards More than Moore and/or beyond CMOS they have to overcome the penguin effect towards a new paradigm. Nobody wants to be the first making the jump because of the fear to lose the game. To reduce the penguin effect STI policy has to establish safe “playgrounds” on which new paradigmatic devices can be explored. Given the importance of the Grand Challenges, these playgrounds could be encouraged through demand led policies such as public procurement of innovation and setting standards that help to generate innovations.

3. Taking the three application areas as representative for all promising application domains for IMS, the Commission should consider implementing instruments that allow the development of pilots, demonstration projects and business models to gain critical mass for market entrance and enhance the usability to the applications generated in the application domains.

4. The Commission should support and facilitate the gathering of strategic intelligence to map and analyse the (potential) value chains in the emerging areas of More than Moore and beyond CMOS. These exercises can help the current IMS stakeholders to develop cross-sector linkages with other European actors or it can guide policy makers to encourage emerging ventures in the ‘white spaces’ thus encouraging a smart specialisation based on IMS as a General Purpose Technology.

5. When promoting a paradigm shift, the Commission should carefully design its measures to avoid early lock-ins in new paradigms that are inferior in the long-term to competing paradigms in the outset. This means that the measure should promote variety in approaches in the future.
6. The study shows that materials and integration technologies (connectivity, packaging etc.) show highest potential for a paradigm shift towards beyond CMOS and/or More than Moore. To establish this new paradigm, the Commission should focus their instruments and programmes on stimulating collaboration between industry and research (universities) to establish a knowledge base, and create human resources and equipment needed.
1. Background of the study on Integrated Miniaturised Systems

1.1 Introduction

This document is the Final Report for the study ‘Integrated Miniaturised Systems for 2015 and beyond’ – SMART 2010/0061, awarded by the European Commission’s DG Information Society and Media to Technopolis Group and its partners SEOR and VDI/VDE-IT. NMTC acted as an associated expert.

The report sets out to explore opportunities to raise Europe’s industrial and technology leadership in ICT, in particular based on new research and technological developments in integrated miniaturised systems. The context for these developments stem from the Lund Declaration, which states that European research must focus on the Grand Challenges. The Innovation Union one of the three Flagship Initiatives of the Europe2020 strategy has set the policy framework for the European Community.

This report covers all activities of the study, including collection of data (desk study, interviews, surveys), documentation and analysis of the results.

1.2 Introduction to the study theme and key questions

1.2.1 Rationale for the study – integrated miniaturised systems and grand challenges

With the new framework programme Horizon 2020 the Commission of the European Union aims at enhancing the competitiveness of European actors as well as lay the platform to respond to grand social challenges foreseeable already today. Integrated Miniaturised Systems (IMS) are a promising field of technology in both generating competitive actors as well as in responding to grand societal challenges. IMS form a broad field containing a huge number of integration technologies, e.g. nano-electronics, packaging, printed electronics and other technologies, based on alternative materials or new physical phenomena’s.

The societal importance of integrated miniaturised systems is undoubtedly high: it is a pervasive technology with applications in a vast range of technologies, in as good as all products of the daily life that holds promise for many new applications that can address our future challenges. Examples of applications domains using IMS are:

- Sustainable development and climate change,
- Energy demand - efficient and secure access,
- Demand for fresh water,
- Global healthcare,
Food safety,
Global convergence of information and communications technologies,
New security applications to reduce conflicts and terrorism,
Sustainable mobility,
Employment in Europe.

Addressing these challenges successfully means retaining and strengthening European competitive capabilities. It means providing answers and solutions regarding to these challenges through developing and offering products and services, which are innovative, merchantable, in a timely manner and cost effective.

An immense number of opportunities for the expansion of already existing markets or – more importantly - the creation of new promising markets will also appear because of the challenges. However, its successes largely will depend upon the mastering of appropriate technologies. Integrated miniaturised systems can play the role as a key enabler to address the grand challenges, and visa versa.

This assignment is primarily focused on integrated miniaturised systems with a special focus on nano-electronics. IMS are perceived as a means that will open the door for a wide range of new electronically based products and services in a range of markets. In general, nano-electronics might play an enabling role for numerous miniaturised systems, because nano-electronics hold some potential for how we might increase the capabilities of electronics devices while we reduce their weight and power consumption and possibly cost. Developments on the forefront of electronics will be most likely driven by trends in further miniaturisation as well as by the integration of more functionality on chips and the increasing emphasis on a system approach. Utilising this functional approach, IMS use properties of devices and materials in completely new ways. IMS are - and will be - indispensable for the competitiveness of future products and even entire European industry and business sectors.

1.2.2 Study objectives
The study has the objective to assist the Commission to prepare for the future of the Horizon 2020 programme, with regard to the competencies and technologies needed to enhance European actors capacity to compete in the area of future integrated miniaturised systems.

The main reason for this study is to acquire knowledge that can support future policy making. DG INFSO aims to develop a systemic view in an application context: What systems will drive nano-electronics development in miniaturised systems? Horizon 2020 has a strong focus on the impact of
Grand Challenges (GC) on future developments in miniaturised systems, but within these challenges, a clear focus should be developed in order to assure that investments in R&D in miniaturised systems will be valuable on the long term.

The study team was asked to give a view on potentially very promising lead markets that might drive the development of nano-electronics and that offer a (partial) solution to needs generated by the grand challenges. Important questions for DG INFSO are: How is the R&D in miniaturised systems evolving and what is an appropriate strategy in Horizon 2020 to strengthen European players? What lead markets are coming up? What does the development of this application field look like and what are the barriers?

Based on current strengths in the EU-industries and in the research communities, the study therefore aims to:

- **Identify** the major technological and scientific challenges and drivers to realise integrated miniaturised electronic enabled systems with whatever high technology (electronics, micro-systems, embedded software, embedded systems) that serve the purpose, with a system view approach and with a view for their implementation in applications in 2020 and beyond;

- **Identify and describe** the strategies and business developments trends for the EU-industry in order to stay at the forefront in developing electronic enabled advanced products;

- **Identify and describe** key application domains where Europe is strong and which could greatly benefit from a largely improved capability to produce advanced nano-electronics systems. The potential impact for the industry and society must be taken into consideration.

In addition, the study should:

- **Take stock** of the advanced research done already up until today, the long term needs for the related high technologies and to establish the relationship between these needs and actions to be started in the near future.

- **Describe** the change in the R&D business models in the area of nano-electronics and identify the European specificities and needs.

Thus an important added value of this study is to bring together several perspectives, that each provide a better view on the requirements for future miniaturised systems:
• The **scientific and technological perspective** which builds on existing strengths in competencies and technologies in the EU, particularly in the electronics industry, research centres and universities;

• The perspective of **market developments**, particularly in those industries that have ICT based products and services in a range of markets, thus the ‘application industries’ but also in the nano-electronics industry;

• The perspective of the **societal challenges** that have influence on the (re-)shaping of markets and business models of both the nano-electronics and application industries.

In short, the task was to answer the questions: which are the most promising applications in the next decades, what are the Grand Challenges’ to which they contribute, which technologies are required to meet these challenges and what is the role of nano-electronics (and associated nanotechnologies) to make these applications possible? We have set a number of clear demarcation lines that helped us to identify and focus on challenges and opportunities in key areas.

1.3 Scoping the study

1.3.1 Scoping ‘grand challenges’

**Societal Grand Challenges** are defined as major challenges to European Union member states as well as to the whole globe. The Lund Declaration of July 2009 defines major societal grand challenges. Those are in the heart of the political strategy for Europe 2020. That strategy is directed towards systemic change in order to be able to solve a number of explicit societal challenges including climate change/global warming; ageing population; public health; pandemics; safety and security; energy, food and water supplies.

The societal grand challenges defined by the Lund Declaration cover a very broad range of topics. To make the study feasible, in consultation with DG INFSO and based on the existing pool of knowledge in the team and in the literature, the consortium chose to choose from the list of Grand Challenges (GC) those where integrated miniaturised systems have a positive contribution for technological development and innovation. The following Grand Challenges were selected:

• Health & Ageing

• Climate change

• Sustainable production

• Sustainable Mobility
1.3.2 Scoping ‘applications’

Grand challenges have a strong impact on various layers of applications. Accordingly, we have looked at application domains and applications that are coming up these four selected grand challenges. We have defined an application domain with broad specifications, in terms of how a set of (functionally similar) products and services can be used to address or solve a particular problem or challenge. Examples for the health area are health care diagnostics or treatments, replacement systems, monitoring, etc.

An application means the purposive use of one or more technologies to generate a special utility on the users side in an application domain or among application domains. It means the use of the principles of one or more technologies for the purpose of obtaining a specific property, performance or function. Applications show typical common features or usages. An application combines or creates technological opportunities in a new format that enable the user (i.e. consumer and/or producer) demands to be met. An application therefore usually encompasses a set of technologies that can, but not need to be similar in origin. An application flows from a particular idea or vision that relates the needs stemming from a grand challenge into tangible consumer and/or producer demands/supplies.

An example of an application domain is: ‘smart infrastructures’ aiming at optimising the traffic flow. Potential applications might be, e.g., route decision systems depending on amount of traffic; intelligent traffic light control to optimise traffic flow; changing street toll to optimise the amount of cars on the street. Alongside the application a number of technological devices (e.g. sensors/actors) and business model innovations (e.g. smart street tolling systems) are needed to transform need into demand. It will require new actors on the market (toll companies, suppliers of smart products to enhance the infrastructure, satellite providers etc.). Traditional technologies like the centralised traffic flow control will be substituted by decentralised autonomous, but interactive new systems.

Finally, the economic trends and drivers to identify and describe the strategies and business development trends are tackled from within the electronics sector (what are the main strategies of the electronic industries in Europe and globally) and from the applications and market that have a strong pull on the electronics sector (e.g. the automotive industry).

1.3.3 Scoping ‘technology’

From a technological perspective the term ‘integrated miniaturised systems’ is aiming at systems that interact electronically and also covers nano-electronics and other technologies. The study, however, is not limited to nano-electronics, but focuses on miniaturised systems in a broader sense. Nevertheless, nano-electronics play and will play an enabling role for numerous miniaturised systems.
Thus, the identification of major technological and scientific challenges and drivers is tackled from within the nano-electronics domain (e.g. challenges related to miniaturisation, IC-design, energy resourcing) as well as from external drivers as for instance a demand for smaller and smarter systems from various application domains. Some of these challenges and drivers will be generic, while others will be domain specific (e.g. ICT-neurons interactions in health domains).

Another boundary condition of our study was that the identified areas for future research should be beneficial for the European semiconductor industry. It should drive competencies in the European industry. As agreed with DG INFSO, although it is possible to approach nano-electronics from a systems perspective, the study focuses on application fields that - at a minimum - are connected to nano-electronics. It is the objective of the study to identify areas where EU research and innovation policy strengthens European competencies on integrated miniaturised systems.

In the analysis of the technological drivers and barriers the inquiry was aiming at two objectives:

**First:** Is the development of CMOS technology expected to continue in the following years? It is a known fact that already today a stage is reached where state-of-the-art semiconductor circuits meet more and more physical limits. Limits concerning the economy of manufacturing, caused by effects of device scaling could be reached even before that.

**Second:** Alongside this search for new devices for signal processing, what new approaches and alternative technologies will be able to replace CMOS technology in the 2020 or beyond timeframe?

On this question, the study identifies what actions seem to be necessary and what trends are under investigation. These approaches aim at technologies that would extend the functional scaling of signal processing substantially beyond the downscaled CMOS. They are represented by the usage of functional diversification – the *More-than-Moore* approach. A second avenue is the development of fundamentally new approaches to meet the requirements of data processing – the beyond *CMOS-approach*.

In the context of these dissimilar trajectories, our investigation set out to analyse and assess several trends and drivers in nano-electronics developments, using the direction of development (scaling, diversification, substitution) as a reference. Pushing for continuous scaling (More Moore) is today accompanied by the simultaneous introduction of additional functionalities such as micro/nano-system, RF, analog, biochips on a conventional logic or memory circuits (More than Moore).

In addition to this, new technologies such as graphene and nanowires (beyond CMOS) are also expected to emerge from the area of nano-sciences and nano-
technologies, possibly leading to breakthroughs for new, unexpected applications. With the respective status of challenges as the starting point, this study investigates the main directions and challenges of the nano-electronic technology development.

1.3.4 Geographical scope
The main focus of the study is on the research and innovation, taking place within the EU. Therefore the focus in this study is on ‘strong potentials’ in terms of technology, applications and industry. The Commission’s aim is to raise the competitiveness of European industry. Opportunities for European companies and research organisations have been used to guide the selection of interesting themes for future research.

1.4 The methodological approach of this study
For this study the team was asked to think beyond the immediate horizon and identify ‘out-of-the-box’ and visionary ideas as well as immediate challenges. For our study it was of highest importance to identify those developments where scientists, representatives of companies (R&D, marketing etc.) as well as intermediaries (representatives of associations) follow established paradigms in integrated miniaturised systems as well as those where these actors are on a step toward a new paradigm.

In innovation sciences it is well known that we have to distinguish two kinds of innovations. On the one hand we perceive radical innovations, on the other incremental. Based on theories developed in the last decade we know that radical innovations are a direct outcome of a shift of the technological paradigm while incremental innovations are changes within an existing paradigm. In incremental innovations the development of technologies follows a trajectory that is defined by the heuristics of a paradigm, whilst in radical innovation the heuristics itself are subject to change. An example for a paradigm is Moore’s law. Moore’s law gives scientist as well as industrial engineers a clear indication what a problem in semiconductor development is and how that problems can be solved best. The paradigm includes accordingly a set of theories and empirical based knowledge elements that direct the work of those who work on R&D in that field. It has to be highlighted that a paradigm does not only consist of technical variables that set the heuristics. Social, political and economic variables are included, too. Accordingly a paradigm can be defined as a set of technical, social, political and economic variables that provides orientation to those that seek for innovations in the area covered by the paradigm. Thus we have also been asked to look for innovative business models, particularly those that are stemming from the Grand Challenges.

Thus the study combines four perspectives to identify paradigmatic changes in applications and technologies: societal, technology & research, economic & industry, as well as policy. In our methodology we have combined the four dimensions by identifying the joint junctions between technology, grand challenges and applications to generate a vision of future usages of miniaturised systems based on existing paradigms, as well as on paradigm shifts identified by the actors in the field. Based on that information we have developed policy recommendations for the European Commission to identify strategies to overcome barriers that prevent European players from gaining a leading edge in the most promising fields of miniaturised systems.

From the outset of the study we have stressed that visionary ideas are mostly defined on a high level of abstraction. Those visionary ideas that could be easily translated into specific application domains or even more specific applications are not readily ‘out there’ to grasp. Any visionary company or research organisation with such ideas would have an interest to exploit these immediately and most likely not disclose what this potential ‘killer application’ would look like. Thus we have attempted to collect visionary ideas connected to the Grand Challenges and linked these to the broader application domains that were selected.

The main challenge in our study was to establish a methodology that could help us to merge the various perspectives to obtain a clear view on future applications and the accompanying technological developments that lead to a marketable response on the grand challenges. As said this proved to be difficult as representatives from different perspectives have completely different levels of abstraction to address future challenges and opportunities. The technologists in R&D departments of companies and research organisation see the potential of technological developments and possible breakthroughs in the coming 5 to 10 years but not necessarily the products and services where these would be applied. The more commercially oriented representatives of technology-oriented companies see the potential for new products in the coming 3-5 years and possibly the new business models that they would need to adopt in the same period. But these would mostly be with an existing paradigm following the roadmaps and market studies that have been published widely already. The visionary thinkers that sketch the urgent demands for the coming decades rarely define these in terms of necessary applications or business models. So it can not be expected that a study of this nature will be able to detect the next generation of ‘killer applications’ on the basis of desk study, surveys and interviews.
As shown in the figure above we have selected an approach that tries to bundle grand societal challenges with application industries and technologies to identify what technologies and industrial configurations are needed to realise future answers to the demands defined by the grand societal challenges discussed in this study.

To do so our study approach consisted of 5 steps to come to a set of future applications and related technological and R&D requirements that could feed into the decision-making of the European Commission for the future:

1. Analysing trends, external influences and drivers for the grand challenges
2. Detecting application domains
3. Deriving potential applications out of the application domains
4. Defining technological requirements and
5. Defining R&D requirements

The **first step** of the study concentrated on those great societal challenges that show the highest connection to integrated miniaturised systems. As aforementioned the search focused on applications related to the four grand challenges "Health & Aging", Climate Change", "Sustainable Production", and Sustainable Mobility". In each four application domains have been identified and clustered.
In a **second step** the identified application domains offered a large numbers of applications with a strong usage of integrated miniaturised systems. Accordingly the long list of applications has been condensed to 3 potential applications\(^4\). The short listing is based on the following criteria:

- High dependency on miniaturised systems to boost this application domain
- High potential to improve societal impact
- High technological challenges to establish an application that responds to the grand challenge
- High likelihood that systemic complexity will hamper the potential implementation in the next 10 years
- Few ethical or regulation issues that potentially block the take up of technologies in the application domain in the next 10 years
- Highly strong European market that could greatly benefit from a largely improved capability to produce advanced nano-electronics systems
- High potential to create strong European market

Based on those three applications in the **third step** we looked at the technological requirements to realise these applications. At this stage the analysis of technological opportunities enters the study. Based on the most recent developments in nano-electronics we have searched for definitions of devices that are capable of realising the identified applications. The design of systems and devices is heavily shaped by technological progress. The following selection criteria are used to further select interesting technologies and their requirements. This has been done based on desk research (such as the patent analysis), interviews with experts, and a second survey.

- High figure of merit
- High prospects of development
- High range of application
- High European competitive edge

\(^4\) A. Miniaturised self-monitoring for personal use in combination with Miniaturised diagnostics or monitoring devices for professional use (Healthy Ageing) B. Applications that enable smart metering, control and sensing in combination with smart grids (Climate Change) C. Advanced driver assistant systems (maritime, road, air) in combination with real-time multi-modal transport information systems for individual users to optimise transport mode and route selection. (Sustainable Mobility)
• High maturity of infrastructure
• High prospects for cost reduction

Finally in a fourth step the R&D requirements in terms of programme and resources are derived and discussed in a workshop with key stakeholders held in February 2012, at the Commission’s premises.

1.5 Methodology

The methodology of the study was based on five methodological steps.

1. At the outset we analysed the trends set by the grand challenges and their (potential) impacts by means of a literature survey. Examples of criteria used for the trend analysis for healthy ageing for instance are: Numbers on the age composition of elderly; Numbers on health cost going along with aging societies; Numbers on care situation of elderly people; Numbers on employment of elderly, et cetera. Based on these trends on drivers promising applications domains and markets were identified also by document analyses.

2. A SWOT analysis of the current strengths in the electronics industry was conducted. Based on a secondary data major strength and weaknesses of the European semiconductor industry were analysed to identify those industrial areas in which the European actors are competitive and were they are not.

3. In parallel to the SWOT analysis a patent inquiry was conducted to identify those areas in which European actors show high patent levels compared to their global competitors. The patent analysis was conducted using WIPO data.

4. Two surveys were sent to actors in sciences, industry and intermediaries.

i) Survey A (Application Survey) aims at identifying key application domains where Europe is strong and which could greatly benefit from a largely improved capability to produce advanced integrated miniaturised systems. A major outcome of the first survey was to rank the different applications identified in the literature study and interviews on five different aspects. These aspects are the impact on society, the impact on economic growth and competitiveness, the systemic complexity of the applications, the current position of the European industry in the application domains and finally, user

Details of the methodological approach is available in Appendix A
acceptance risk. A second outcome was to identify the main barriers and challenges in order to realise IMS.

In order to rank the applications it was vital to reach respondents that are knowledgeable of IMS related applications for the Grand challenges. This mean that we targeted companies, universities and research institutes that provide research, services and products for applications related to IMS and the four Grand Challenges. As there is no information on the population, we cannot assess the representativeness of the survey. However, for our purpose, the main aim was to ensure that our respondents are knowledgeable about the subjects of the survey. Moreover, we made sure that our sample was spread around different organisations, countries and the Grand Challenges and applications domains, in order to avoid bias.

Within these organisations the survey was aimed at Research managers, Department leaders and consultants within universities and research institutes and R&D management and general management within companies, as these groups would be able to have an oversight of the main developments of IMS applications within the Grand challenges. Having an oversight is important as the respondent were asked to rank a diverse range of applications. More details about the respondents, shown in appendix xxi, show that we succeeded in our approach.

The survey was sent to 1,938 candidates out of whom 314 responded and 263 completely filled in the survey. All European countries are represented in the survey. Respondents were asked to choose a Grand Challenge and rank each application within this Grand Challenge on each of the five aspects. The response rate is divided quite evenly among

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6 In practice it is difficult to know upfront whether a respondent applies IMS in products, services or research. However, in the selection of respondents we specifically targeted organisations and people that are likely to apply IMS.

7 The population would be all organisations that provide services, products and research related and the four Grand challenges and IMS.

8 Half of the respondents say they do not apply IMS in their services or products. This means we are able to split the sample in two respondent categories in order to have a control group. Results for both groups are actuallys highly comparable. Average scores for the applications are even higher for those who do not apply IMS, while standard deviations are lower.

9 Respondent selected the applications they would rank themselves. The advantage of this approach is that we made sure that respondents were knowledgable of the applications. In practice many respondents who mentioned that their organisation is involved in a specific Grand Challenge, eventually choose a different Grand challenge for the ranking of the applications.
the Grand Challenges, except for sustainable mobility. As the respondents ranked each application we have a minimum of 54 observations (for sustainable mobility applications, for the other Grand Challenges the number of observations is around 75 to 79) for each aspect for each application. This is sufficient for making conclusions regarding each application. However, this response rate does not allow us to further analyse answers for different categories of respondents. The ranking of the applications is discussed in chapter 3.

ii) The second Survey T (Technology Survey) was based on the results of the secondary analysis of the technological developments in integrated miniaturised systems. The main focus of the second survey was to identify technological variables and attributes that currently and in the future will direct technological trends in integrated miniaturised systems. Furthermore the survey inquired the main barriers and drivers in integrated miniaturised systems as well as the competitive position of the European actors in a global competition. The survey was send to more than 3000 candidates on October 19th 2011. In total 432 candidates responded.

5. The results of the secondary analysis, the SWOT and the surveys was validated by interviews with representatives of industry, sciences and intermediaries. Harmonised interview guides structured the interviews conducted. A list of all the interviewees can be found in Appendix A.

1.6 The structure of this report

The remainder of this report is structured as follows:

Chapter 2 discusses the societal drivers and opportunities to realise integrated miniaturised electronic enabled systems. The societal challenges form an impetus for the demand for new products and services of IMS, either driven by consumer and intermediary demand on the market and/or answering to public policies that deal with societal problems. This chapter identifies and describes the major societal challenges and drivers and finds pointers of where IMS will offer potential solutions. For this chapter, the study team used a number of filtering processes to identify those specific challenges that ask for IMS solutions. Main sources include a screening of strategic research agendas\(^\text{10}\), roadmaps and other literature.

Chapter 3 discusses the key application domains where Europe is strong and which could benefit from improved capability to produce advanced nano-

\(^{10}\) For instance Strategic Research Agenda of the European Technology platform on Smart systems Integration (2009) www.smart-systems-integration.org
electronics systems. In the chapter, the earlier identified application domains are being assessed from an economic perspective. It takes the review of the grand challenges and the resulting long list of application domains as a point of departure. Key elements in this chapter are (future) market potential and competitive position.

Chapter 4 identifies the main strategies and business development trends in the IMS industry, with a specific focus on Europe and European industry. It describes how changes in market dynamics as well as technological developments have altered - and continue to alter – business strategies and business models\textsuperscript{11}. Based on this analysis, specific future needs for European industry are identified to maintain competitive edge and stay at the forefront of developments.

In Chapter 5, competencies and technologies needed for integrated miniaturised systems are identified. It gives an overview on the state of the art in integrated miniaturised system technologies and the major technological and scientific challenges and drivers.

Chapter 6 finally provides the main conclusions and recommendations that can be drawn from this study.

\textsuperscript{11} A business model describes the rationale of how an organization creates, delivers and captures(economic, social, or other forms of) value.
2. Societal drivers to realise integrated miniaturised electronic enabled systems

This chapter discusses the societal drivers and opportunities to realise integrated miniaturised electronic enabled systems (IMS). Our society faces a number of challenges and developments of IMS offer potential solutions. The societal challenges form an impetus for the demand for new products and services of IMS, either driven by consumer and intermediary demand on the market and/or answering to public policies that deal with societal problems.

The purpose of this chapter is to identify and describe the societal challenges and to find pointers of where IMS will offer potential solutions. For this chapter, the study team used a number of filtering processes to identify those specific challenges that ask for IMS solutions. Main sources include a screening of strategic research agendas\(^{12}\) and roadmaps.

In the first section we will stress that grand societal challenges form a basis for developments in research, development and innovation in the domain of IMS. We will show that not only IMS provides technological solutions; the grand challenges also pull the development of IMS towards societal issues.

In the subsequent sections we will focus on Grand Societal Challenges. The sections elaborate upon the trends and drivers underpinning the challenges, and the effects of these trends and drivers for the Grand Challenge. We took a broad focus in the analysis of the Grand Challenges: societal, environmental, technological, economical and political trends are intertwined and potentially important for the development of and the technological solutions to the particular Grand Challenge.\(^{13}\) Section 2.2 provides insight in the selection of grand challenges; the subsequent sections deal with selected challenges. Section 2.3 deals with the challenge health and ageing; section 2.4 with climate change; section 2.5 with sustainable production and section 2.6 with sustainable mobility. Each section will start with sub-section that presents an analysis of the grand challenge, taking into account the trends and drivers underpinning the grand challenge. In the second sub-section, an analysis will be made of the first triggers for applications relevant to the grand challenge. Please note that each section on the Grand Challenges (2.3 – 2.6) is based on

\(^{12}\) For instance Strategic Research Agenda of the European Technology platform on Smart systems Integration (2009) www.smart-systems-integration.org

\(^{13}\) Here, we pragmatically applied a heuristic analytical tool from technology foresight practice, i.e. the STEEPV-analysis (Social, Technological, Economic, Environmental/Ecological, Political and Value-based issues).
extensive study. Each section goes accompanied with an appendix that elaborates further on the grand challenge.

Chapter 2.7 summarises the main findings of this chapter.

2.1 Grand Societal Challenges – the basis for research and development

Research, development and innovation are crucial for our society. Investments in research, development and innovation by public and private bodies lead to increased business opportunities, new innovative products and services delivering competitive advantages. Innovation leads to growth in creation of jobs, prosperity, quality of life and public goods available – and will offer solutions to challenges to our society.

The European Union is facing a number of Societal Grand Challenges (GC), for instance identified in the Lund Declaration14. Therefore, the GCs are at the heart of Europe 202015 which is specifically directed towards systemic change in order to solve societal challenges including climate change/global warming; ageing population; public health; pandemics; safety and security; energy, food and water supplies. With regard to these GCs, the European Commission’s Horizon 202016 identifies a pivotal role for research and development and states “smart investment, notably in research and innovation is vital in order to maintain high standards of living while dealing with pressing societal challenges”17.

Integrated miniaturised systems (IMS) are an important ingredient to help solving the Grand Challenges. It is pivotal to this study, to find intersections between the technological potential of integrated miniaturised systems and the societal demands of the EU. This requires analysis of the grand challenges posed to our society.

Many interesting potential applications of IMS offer solutions to Grand Societal Challenges. Technological developments in the domain of IMS push applications that have positive effects on a range of societal challenges. Interestingly, the grand societal challenges pull development of IMS currently, thus influencing the development of miniaturised systems. This guiding effect of grand challenges was illustrated in interviews and strategy documents, which show that societal challenges play an important role in strategic

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14 July 2009
15 COM(2010) 2020
16 COM(2011) 808
17 Ibid., pg. 2.
decision-making on R&D for a variety of actors such as policy-makers\textsuperscript{18}, companies\textsuperscript{19} and research institutes (see Figure 2 below).

Figure 2  The guiding effect of Grand Societal Challenges on actors in R&D.

Two mechanisms underpin the guiding effect of the grand societal challenges as basis for research and development: societal responsibility and potential valorisation or commercialisation opportunities.

Companies show willingness to develop towards societal challenges as a part of taking corporate responsibility. This becomes formally visible in the many sustainability, corporate responsibility or annual reports, notably of large companies; but also smaller companies may see this as a responsibility. Moreover, societal trends related to the societal challenges provide many business opportunities. Public incentives (e.g. R&D subsidies) and regulations (e.g. performance standards), stimulate technological development dealing with societal challenges, for instance in the case of renewable energy technologies. Also, the nature of the trends underpinning the societal challenge may offer business opportunities. A clear example of the latter is the “silver market”\textsuperscript{20} emerging in relation to healthy ageing: a relatively wealthy generation that is used to technology will retire and can use innovations to improve their quality of life.

For researchers at public institutions responsiveness to grand challenges is also often favourable. In many countries public facilities are in place that fund R&D dedicated to societal challenges such as sustainability, health care and ageing, et cetera. If researchers succeed to make their research activities and results relevant for societal challenges, this opens opportunities to source funds, earmarked for a specific challenge. In addition to this, literature shows that generally researchers tend to be motivated to make their work relevant to society\textsuperscript{21}.

2.2 The selection of grand challenges

In consultation with DG INFSO, the consortium choose to narrow the list of Grand Challenges down, thus providing a greater depth to this study. Two main considerations were to include those challenges where IMS can have a

\textsuperscript{18} E.g. the Europe2020
\textsuperscript{19} E.g. the many sustainability reports of larger companies
\textsuperscript{20} F. Kohlbacher & C. Herstatt, 2008. The silver market phenomenon: business opportunities in an era of demographic change
significant impact and where data on future directions will be accessible\textsuperscript{22}. This study elaborates upon the following Grand Challenges:

1. Health & Ageing
2. Climate change (incl. sustainable energy)
3. Sustainable Production
4. Sustainable Mobility

The GC of health and ageing primarily deals with the ageing populations and associated challenges to the health system. Climate change puts limitations to our consumption pattern, especially of our energy production and use. Sustainable production, in addition to energy consumption, has a wider scope on consumption of all other resources. Although energy consumption is important to sustainable production as well, we chose to focus on energy consumption in the context of ‘climate change’ to avoid duplications. Similarly, all consumption of energy and materials for mobility are included in the discussion of ‘sustainable mobility’. Sustainable mobility deals with all aspects of mobility that currently impact our environment, our living conditions as well as the economy.

2.3 Health and Ageing

2.3.1 The societal challenge of health and ageing: analysis

The main societal challenge in this domain is to support healthy ageing throughout the lifespan, aiming to prevent health problems and disabilities from an early age, and tackling inequities in health linked to social, economic and environmental factors.

The ageing population in the EU and other parts of the world will lead to a raised demand for healthcare while the working population decreases\textsuperscript{23}. It will most likely push up healthcare spending, however, if people remain healthy as they live longer, the rise in healthcare spending due to ageing could be halved. Better-adapted healthcare services and prevention of chronic diseases could reduce public spending. Moreover, new technologies can potentially contribute

\textsuperscript{22} The GC of security has not been selected, although it is a promising application field of miniaturised systems. We dropped this topic for a well-known problem: data on R&D on security technology is often hard to access: respondents and interviewees do not have the opportunity to speak freely on the nature of the content of their work and joint agenda setting is not public. Since climate change is a very broad ‘challenge’ we decided to focus on the challenges relating to the depletion of resources and sustainable production. Specific sustainable energy challenges are thus part of this.

\textsuperscript{23} WEF, 2008 (The Future of Pensions and Healthcare in a Rapidly Ageing World Scenarios to 2030)
to future sustainability by improving healthcare and health systems, monitoring, treatment and assistance.\textsuperscript{24}

A summary of the main trends and drivers underpinning the grand challenges and the consequences of this for the challenge are displayed in Figure 3. It builds on a wide variety of visionary sources\textsuperscript{25} and presents a concise overview of the analysis of the grand challenges, presented in Appendix C.

\textsuperscript{24} The impact of ageing on public expenditure: projections for the EU25 Member States on pensions, health care, long-term care, education and unemployment transfers (2004-2050) Report prepared by the Economic Policy Committee and the European Commission (DG ECFIN)

\textsuperscript{25} Main sources include:

- Special issue on healthcare. Healthy ageing and the future of public healthcare systems, 2009. European Commission DG research part of the EFMN publication series
- Megatrends, a broad outlook on innovation, 2010. TNO
- User Needs in ICT Research for Independent Living, with a Focus on Health Aspects, 2006. European Commission (Directorate-General Joint Research Centre) and Institute for Prospective Technological Studies, Brussels 2006, Gérard Comyn, Silas Olsson and Rainer Guenzler, Rukiye Özçivelek, Dieter Zinnbauer and Marcelino Cabrera
- The No-Computer Virus”, Economist, 28 April 2005. The Economist
- “Medical devices: managing the mismatch: an outcome of the priority medical devices project” WHO Geneva, 2010. WHO
- Value for money in health spending, 2010. OECD
Given the above-stated aspects of the grand challenge of health and ageing, the EU will need to cope with:

- Demographic change
- Balancing equity and cost efficiency
- Cost-benefit analysis with regard to emerging medicine and preventative measures
- Prevention and rehabilitation
- New concepts for the labour market and pensions
• New health systems and technologies, and the hospital of the future

• Healthy in the home concept

IMS offers potential solutions for a cheaper and more effective health care system that including care for elderly people.

2.3.2 Health and ageing: pointer for IMS applications

Based on desk study, the survey amongst stakeholders that apply miniaturised systems\(^{26}\) and interviews pointed towards applications with relevance for healthy ageing, including\(^{27}\):

- **Applications for miniaturised diagnostics for quick and easy-to-use diagnostics for professional use where rapid information on disease characteristics is essential, or for self-monitoring for personal use (point-of-care). In a first step, portable diagnostic systems will be developed\(^ {28}\). Important technological opportunities that miniaturised systems offer are biosensor modules, integration of different modules and optimisation, operation and validation of biosensing systems based upon medical data. Important building blocks are biosensors and Labs on a Chip. One step beyond, miniaturised systems may enable health management, e.g. via self-monitoring for personal use, thus safeguarding ease of use, and invisibility of the monitoring device. Miniaturised systems play a pivotal role in developing small diagnostics, both for continuous monitoring as for quick one-off diagnostics handling. Promising S&T developments of miniaturised systems for healthy aging are among others\(^ {29}\):
  - Biosensors;
  - Low-power wireless communication;
  - Energy scavenging devices; and
  - Autonomous sensing miniaturised devices.

- **Minimally invasive therapy.** Integrated systems will deliver new functionalities that may provide assistance during therapy. Miniaturised systems open up opportunities for treatment, enabling independent living,

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\(^{26}\) Survey A.

\(^{27}\) The applications mentioned are based on the Strategy for the Future of Health; Renata G. Bushko, 2009, p31; the Strategic Research Agenda of the European Technology platform on Smart systems Integration (2009) [www.smart-systems-integration.org](http://www.smart-systems-integration.org) - as well as on interviews (primarily with IMEC, and the visionary documents provided in Appendix C.


\(^{29}\) Strategic Research Agenda of the European Technology platform on Smart systems Integration (2009) [www.smart-systems-integration.org](http://www.smart-systems-integration.org)
and for monitoring and optimisation of medical treatment – applications may be envisaged for both clinical settings, as for home use. Important promises of miniaturised systems are:

- Novel transducers
- Biocompatible smart robotics
- Biopsy devices and tools

The above-mentioned opportunities already display elements of a broad vision of devices that enhance the quality of life by assistive technologies enabling assisted living. This comprises smart ambient technologies, ICTs that enable inclusiveness to society from the home chair, etc. Applications of IMS for ambient assisted living are clearly displayed by the range of projects in the frame of AAL\(^\text{30}\). The many projects at the level of MS show a range of similar applications.\(^\text{31}\)

2.4 Climate Change

2.4.1 The societal challenge of climate change: analysis

The main societal challenge with regard to climate change is to mitigate the process of climate change, by finding new ways to organise our economic growth and societal welfare that reduce the emission of greenhouse gases.\(^\text{32}\)

Human activity impacts the climate by the mechanism of the greenhouse effect: a mixture of gases trap energy from the sun in the atmosphere. Human activities such as industry, traffic, etc., lead to higher emissions of gases and thus to amplification of the greenhouse effect. A notable consequence of the amplified greenhouse effect is an increase in temperature. In turn, an increasing temperature leads to a range of impacts such as defrosting of the North and South Pole, flooding, and et cetera. Since the first Industrial Revolution the average temperature has raised dramatically – i.e. the so-called hockey stick curve – hand-in-hand with the increase of emissions due to industrialisation. The concentration of atmospheric CO\(_2\) has increased from about 280 parts per million (ppm) in pre-industrial times to more than 387


\(^{32}\) Grand Challenge 4 on sustainable transport has a certain overlap with this challenge and is therefore out of scope of this section.
ppm in 2008\textsuperscript{33}. At the same time, the temperature in our climate increased dramatically and is expected to continue to increase.\textsuperscript{34}

The main trends and drivers underpinning the grand challenge of Climate Change and the key consequences are displayed in Appendix D.

Figure 4. Key drivers and key consequent challenges for the Grand Challenge

Climate Change

<table>
<thead>
<tr>
<th>Key drivers</th>
<th>Key consequent challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Societal</strong></td>
<td><strong>Societal</strong></td>
</tr>
<tr>
<td>• Global increase of population and urban spread</td>
<td>• Increasing demand for (fossil) energy</td>
</tr>
<tr>
<td>• Changing lifestyles lead to more households (EU)</td>
<td>• Societal incentive to mitigate climate change</td>
</tr>
<tr>
<td>• Increasing wealth (non-EU)</td>
<td><strong>Environmental</strong></td>
</tr>
<tr>
<td>• Emerging societal willingness to pay for more sustainable solutions</td>
<td>• Flooding, spread of (exotic) diseases, health issues, drought (endangering food and water supply), desertification, etc.</td>
</tr>
<tr>
<td><strong>Environmental</strong></td>
<td><strong>Technological</strong></td>
</tr>
<tr>
<td>• Rising temperature due to greenhouse gases</td>
<td>• Alternative energy sources become economic viable, notably solar power.</td>
</tr>
<tr>
<td>• Local emission of greenhouse gases</td>
<td>• Fossil fuels become cleaner</td>
</tr>
<tr>
<td><strong>Technological</strong></td>
<td><strong>Economic</strong></td>
</tr>
<tr>
<td>• Development of non-fossil energy technologies (wind, solar, nuclear, etc.)</td>
<td>• Increasing demand for cheap (fossil) energy</td>
</tr>
<tr>
<td>• Development of end-of-pipe cleaning of fossil fuels</td>
<td><strong>Political</strong></td>
</tr>
<tr>
<td>• Development of more energy-efficient technologies</td>
<td>• Policies in place that stimulate energy efficiency and renewable energy technologies</td>
</tr>
<tr>
<td><strong>Economic</strong></td>
<td><strong>Political</strong></td>
</tr>
<tr>
<td>• Economic growth is still coupled to increasing energy intensity (esp. extra-EU)</td>
<td>• Broad policy incentives to stimulate the development of alternative energy sources</td>
</tr>
<tr>
<td>• Increasing purchasing power</td>
<td>• Threat of misaligned policies</td>
</tr>
<tr>
<td><strong>Political</strong></td>
<td><strong>Policies</strong></td>
</tr>
<tr>
<td>• Partial political will to mitigate climate change</td>
<td><strong>Technologies</strong></td>
</tr>
<tr>
<td>• Other policy rationales favour mitigation of climate change, i.e. security of supply and depletion of resources</td>
<td><strong>Technologies</strong></td>
</tr>
<tr>
<td>• Fragmentation of national energy markets and policies</td>
<td><strong>Policy</strong></td>
</tr>
</tbody>
</table>

Source: This STEEP analysis is based on a variety of future studies, explorations and roadmaps\textsuperscript{35}, see Appendix D.

\textsuperscript{33} Richardson et al., 2009
\textsuperscript{34} IPCC, 2007
\textsuperscript{35} A more extensive list is provided in the Appendix, but includes:

- The European Environment – State and outlook, 2010. European Environment Agency
A main challenge for the EU is to generate and use energy, while minimising the emissions of GHG. IMS provide opportunities for both energy generation and saving of energy.

2.4.2 Climate change: pointers for IMS applications

Desk study, the survey amongst stakeholders that apply miniaturised systems\(^{36}\) and interviews pointed towards applications with potential for dealing with climate change, including:

- **Renewable energy technologies.**\(^{37}\) Wind and solar power are two completely different sets of application domains. Integrated miniaturised systems have promise for the control and power management of wind power; this is more about engineering and streamlining of the wind power technology. Solar power is less mature and radical semiconductor innovation may change the nature of the end technology completely. In the case of wind power, miniaturised systems have a profound promise for switching energy and storage of energy: \(^{38}\)
  - Improved power transistors, eventually shifting to higher junction temperatures, higher current density and break down voltage, by moving to non-silicon switches
  - Improved AC/DC conversion;
  - New materials and surface area handling (3d) improving batteries (solid-state, thin-film, etc.)

\(^{36}\)Survey A.

\(^{37}\)See for instance the Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES for a range of applications of IMS to renewable energy technologies.

\(^{38}\)This development was described already 15 years ago (B.J. Baliga, “Trends in power semiconductor devices”, IEEE Trans. Electron Devices, vol 43, pp. 1717-31, 1996), but development of non-Si is still high on strategic research agendas of individual institutes.

- Global megatrends – (SOER), 2010. European Environment Agency
- Regional Environmental Change: Human Action and Adaptation, 2010 International Council for Science (ICSU)
- Towards a Green Economy, 2011. UNEP
- The Eco-Innovation Challenge: Pathways to a resource-efficient Europe, 2010. Eco-Innovation Observatory
- World Energy Outlook, 2008. OECD/IEA
- Energy Outlook 2030, 2010. BP
These promises also go for solar power, especially for smart photovoltaic modules. On top of that, miniaturised systems also hold promise for the photovoltaic cell itself. As a photovoltaic cell in a way is an upside down semiconductor, the knowledge development in this area is large. The main drivers are cheaper and more efficient solar cells. Promises include 39:

- Crystalline silicon cells: thinner wafer handling, Silicon feedstock optimisation, etc.
- Stacking photovoltaic: 3D-technologies, improved cooling and better and smaller interconnections thus increasing the surface of the cell
- Printed photovoltaic: organic cells, thinner films, and flexible applications.

- **Smart grids.** The transmission and distribution systems for distribution of electricity are relatively old and make limited use of digital control technologies. Moreover, injected energy of renewable sources poses several challenges to the distribution grid (load balancing, supply/demand management, grid instability). Investments in smart grids have intensified and there is a clear role for IMS 40. The smart electricity grid integrates miniaturised systems at all steps of the value chain, building on advanced sensing, switching, communication and control technologies for advanced generation and distribution technologies.

Miniaturised systems for smart grids involve primarily incremental change, in the following areas: 41

- Integrated communication technologies
- Sensing and measurement technologies
- Advanced components can control
- Improved interfaces and decision support.

Miniaturised systems have a key enabling role for the following processes: fast communication for load management, fast power switching, real-time pricing mechanisms, and autonomous sensor networks.

40 IC Market Drivers, 2011. A Study of Emerging and Major End-Use Applications Fueling Demand for Integrated Circuits
41 See Smart Grid: Enabler of the New Energy Economy, 2008, A report by Electricity Advisory Committee for the U.S. Department of Energy; The European Smart Meters Industry Group (ESMIG) defines four functionalities, which are all supported by IMS: remote reading, two-way communication, advanced tariffing & payment and remote disablement and enablement of supply.
In addition, developments in the Beyond CMOS strand promise greater energy-handling capacities. Semiconductors with a wide band gap, such as Gallium Nitride hold promise for fast switching, of high voltage and current power electronics at high temperature\(^{42}\).

2.5 Sustainable production

2.5.1 The societal challenge of sustainable production: analysis

The main challenge for sustainable production is to produce goods and service, while reducing the consumption of energy and (scarce) materials; increased resource efficiency and avoiding the uptake of scarce resources and prevention of harmful emissions is thus key.

Production of goods brings along consumption of energy, resources and outputs that may harm our environment. Because of the increasing productivity of our society, we face a challenge to be able to increase energy\(^{43}\) and resource efficiency of production, while minimising the environmentally hazardous output. This is due to the fact that environmental impacts occur at every step of value chains. Energy and resources are used, while emissions are released into water, air, and soil.

The main cause of the continued deterioration of the environment is the unsustainable configuration of our society in producing and consuming, which causes degradation of ecosystems and the use of ecosystems. Unsustainable production thus brings along a number of societal problems, such as shrinking water reserves and forests, depletion of scarce materials, extinction of species and erosion of fertile land. Extraction of large amounts of materials furthermore impacts land cover and biodiversity.

The main trends and drivers underpinning the grand challenge of sustainable production and the key consequences are displayed in Appendix E.

\(^{42}\) To be found on many (secret) strategic research agendas of the various large IMS research institutes.

\(^{43}\) The challenge of a sustainable energy supply is already dealt with in the section on climate change.
IMS offers a range of applications that could make production more energy and material efficient; thus decreasing the net consumption of resources.

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44 This includes – but is not limited to the following sources (see Appendix E for a full overview):
- **Global megatrends – (SOER), 2010. European Environment Agency**
- **Towards a Green Economy, 2011. UNEP**
- **Global Material Flow Database, 2010. Sustainable Europe Research Institute, Vienna.**
- **The Eco-Innovation Challenge: Pathways to a resource-efficient Europe, 2010. Eco-Innovation Observatory**
- **EFFRA, 2010. Strategic multi annual Roadmap, Brussels**
2.5.2 Sustainable production: pointers for IMS applications

Desk study, the survey amongst stakeholders that apply miniaturised systems\(^\text{45}\) and interviews pointed towards applications with potential for sustainable production, including:

- **Applications that increase supply chain and logistics efficiency (e.g. RFID, wireless sensor networks, machine-to-machine communication)**\(^6\).
  The promise in this area is not necessarily of totally newly developed IMS, but merely engineering and tailor made solutions for sensor networks, robotics and virtual factories based on solid supply chain management\(^47\). Promising developments of miniaturised systems are digital factories\(^48\), which require the development of small and autonomous communication systems that would allow machine-to-machine communication thus ensuring more efficient production processes. This demands improvements of the power supply, as well as set new requirements to the integrated system and its packaging. Again, high temperature resistant systems based on non-silicon chips would have large potential for control functions in production processes. Printed systems would lower the cost of RFID, which allows increasing digital monitoring and control, thus increasing logistics efficiency.

- **Applications that enable more resource and energy efficient production processes (e.g. combined heat power; flexible and adaptive production; system optimisation; intelligent machinery; zero defect manufacturing)**.
  The role of miniaturised systems in sustainable production is rather focussing on monitoring and control of processes, thus increasing the efficiency of production. Miniaturised systems offers a range of technologies to increase efficiency of production:\(^49\)
  - Quicker and better sensing and measurement systems, improved sensor systems for example for chromatography
  - Wireless communication for machine-to-machine communication
  - Improved power switching\(^50\)

\(^{45}\) Survey A.


\(^{48}\) EFFRA (2010) strategic multi annual Roadmap, Brussels

\(^{49}\) Ibid.

\(^{50}\) Ibid.

\(^{50}\) Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES for a range of applications of IMS to renewable energy technologies.
Non-silicon systems and improved packaging, enabling the system to operate in more demanding environments.\textsuperscript{51}

Moreover, the downsizing in the IMS domain leads to reducing packaging and devices sizes. Combined with lead and halogen free products, this downsizes the footprint of IMS.\textsuperscript{52}

\subsection*{2.6 Sustainable mobility}

\subsubsection*{2.6.1 The societal challenge of sustainable mobility: analysis}

Sustainable mobility systems are transportation systems that meet society’s economic, social \textit{and} environmental needs.\textsuperscript{53,54} The main challenge to sustainable mobility is to improve efficient transportation and mobility (thus including the reduction of congestion), while reducing the environmental impact and increasing safety.

Economic growth and demographic shifts are placing an increasing and changing demand on transportation capacity (\textit{population growth, economic growth}), creating different patterns of transportation use (\textit{urbanisation, networked businesses}) and creating the need for improved access to transportation and mobility (\textit{ageing population and an multi-national integrated transport system}).\textsuperscript{55} At the same time the environment impact of transportation has to reduce to meet emissions regulations and limit climate change. The potential to increase transportation capacity is limited, particularly in developed countries and particularly in urban areas, and therefore increased demand will have to be met through better and more effective use of networks and changes in mobility behaviours.

The main trends and drivers underpinning the grand challenge of sustainable production and the key consequences are displayed in Appendix F.

\begin{footnotesize}
\begin{itemize}
    \item 51 Based on the interviews; to be found on (undisclosed) strategic research agendas of individual institutes
    \item 54 White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, COM(2011) 144 final
    \item 55 See for instance R. Phaal, 2002. Foresight Vehicle Technology Roadmap - Technology and Research Directions for Future Road vehicles, Centre for Technology Management, University of Cambridge
\end{itemize}
\end{footnotesize}
Figure 6 Key drivers and key consequent challenges for the Grand Challenge sustainable mobility

Key drivers

Societal
• Demographic: more and older people, urban sprawl
• Changing lifestyles: more households, more personalized products and services
• Globalisation

Environmental
• Increasing impacts on environment due to exhaustion gas and fossil-fuel-based transport (greenhouse gases)

Technological
• Emergence of non-fossil fuel based transportation
• Improvement of power trains for all vehicles
• Generic technologies enabling improvement of vehicles or transport systems (e.g. ICT)

Economic
• Economic growth: more consumption
• Globalisation: increasing foreign trade

Political
• EU Multilevel governance alignment issues
• Safety regulations
• Political willingness to ‘green’ transport

Key consequent challenge

Societal
• Increased use of transport:
  • Worsening congestion
  • Emissions of gases
  • Increasing interdependencies and complexity of transport systems

Environmental
• Increasing pressure on the environment
  • Greenhouse effect
  • Pollution of air, soil and water

Technological
• Opportunities for more efficient transport systems with less negative externalities

Economic
• Increasing mobility

Political
• Increasing interdependencies and complexity of transport systems
• Incentives for safer and more sustainable transport systems

Source: This STEEP analysis is based on a variety of future studies, explorations and roadmaps66, see Appendix F.

66 Including, but not limited to:

• Reported in TRANSvisions, Final Report: Report on Transport Scenarios with a 20 and 40 Year Horizon, March 2009
• White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, COM(2011) 144 final
• In the UN’s medium growth rate forecast; U.S. Census Bureau & UN Department of Economic and Social Affairs report: World Population To 2300 (2004)
• TRANSvisions, Final Report: Report on Transport Scenarios with a 20 and 40 Year Horizon, March 2009, Coordinated Tetraplan A/S, Copenhagen, Denmark
• Megatrends: a broad outlook on innovation, TNO, 2010
• Infrastructure to 2030 Volume 2 – Mapping Policy for Electricity, Water and Transport, OECD, 2007
• U.S. Department of Transportation, Freight Facts and Figures 2009, Coordinated Tetraplan A/S, Copenhagen, Denmark
• T. Wiesenthal et al., Research of the EU automotive industry into low-carbon vehicles and the role of public intervention, JRC Technical Notes, 2010
2.6.2 Sustainable mobility: pointers for IMS applications

Desk study, the survey amongst stakeholders that apply miniaturised systems\(^{57}\) and interviews pointed towards applications with potential for sustainable mobility, including\(^ {58}\):

- **Advanced driver assistance systems.** A first step in assistance of driver is intelligent support to the driver in observing its environment. A second step would be networked driver assistance systems with telematics links to traffic management centres, other vehicles and service providers. The potential of miniaturised systems is very high. The links of sensors, data processing and consequent actions demands for extremely reliable systems, posing challenges to e.g. sensing (memory), processing and interfacing. A networked assistance system would demand for more complex integrated systems, which allow networked communication (energy supply) and data processing.

- **New propulsion systems.** For sustainable transport it would be necessary to be less dependent on fossil-fuelled internal combustion engines. Alternatively, Hybrid electric propulsion and full electric vehicles are identified as more sustainable transport means. These vehicles require advanced power management, as well as smart grid integration in which integrated miniaturised systems may play a significant role. Improved energy-handling properties of wide band gap semiconductors (Beyond CMOS) are promising to play a significant role here. Improved packaging of integrated miniaturised systems can ensure high temperature and fast switching power applications.

2.7 Conclusions

Grand societal challenges form the basis for research, development and innovation in the field of IMS. The development of applications of IMS may have a large potential in dealing with certain grand challenges. This chapter presented the outcomes of an analysis of the main drivers and trends underpinning the grand societal challenges. As IMS are enabling to other technologies, the number of promising applications that could help address the Societal Grand Challenges is potentially extremely large. For healthy ageing, improved diagnostics, monitoring, minimal invasive therapy and assisted living/distant care are promising applications. For climate change the focus lies on renewable energies (wind, photovoltaic) and its transport in smart grids. Integrated systems show large potential for applications in

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\(^{57}\) Survey A.

\(^{58}\) Strategic Research Agenda of the European Technology platform on Smart systems Integration (2009) www.smart-systems-integration.org
streamlining and optimisation of production processes for the grand challenges of sustainable production. Sustainable mobility can benefit from integrated miniaturised systems in driver assistance systems and improved propulsion.

The next chapter will elaborate this exploration of entrance points for IMS to solve grand challenges, taking into account the industrial strengths of the Europe. Subsequently, chapter 4 will elaborate on the business models and chapter 5 on the technological opportunities derived from the potential application areas.
3. Key application domains where Europe is strong – lead markets

3.1 Introduction and methodology

One of the main objectives of this study relates to the identification of key application domains and applications in which integrated miniaturised systems (IMS) are key and which offer credible future prospects in terms of demand as well as supply, i.e. capabilities to design, create, develop and/or produce. This chapter discusses the earlier identified application domains from an economic perspective. It takes the review of the grand challenges and the resulting long list of application domains of chapter 2 as a point of departure. Key elements in this chapter are (future) market potential and competitive position.

The number of potential applications that could benefit from IMS is virtually unlimited. The application domains (pointers for applications in chapter 2) show a clear and balanced link with the grand challenges. However, in order to arrive at a final and meaningful selection of promising key application domains and applications, two further steps have to be made:

- An analysis and review of existing and future trends and developments in each of the application domains, based on existing external accounts, taking account of technological, economic and other factors (step 1)
- An inventory of how the broader IMS-stakeholder community perceives and valuates the current and future opportunities and challenges in each of the application domains (step 2).

The first step essentially provides the opportunities and challenges for each of the application domains as seen and assessed on the basis of existing studies and other relevant material (e.g. ETP roadmaps, company annual reports). The results of the first step are described in section 3.2. The second step of mapping and analysing these future opportunities and challenges from a stakeholders’ point of view is taken up in section 3.3. Both interviews and an online survey among a sizeable sample (see Appendix B) of stakeholders were used to map and assess the opportunities and challenges. These apply to technological and innovation challenges, but also to the prospects for new products, markets and business models. An important objective of the survey also was to further investigate and ‘validate’ the various application domains. The group of stakeholders in both the interviews and the survey included technological and market experts as well as managers in manufacturing companies (both IMS manufacturing companies and IMS customer industries), consultancies, research institutes and universities. The survey was sent to almost 2,000 stakeholders and a response rate of 14%.

The review, the survey and the interviews served as a basis for the final selection of most promising application domains and applications. This final selection - resulting in the choice of three priority application domains - was
made on the basis of the survey results combined with expert judgment. These priority application domains are the basis for further analysis, in particular on competencies and technologies to realise future miniaturized systems, in chapter 5.

3.2 Application domains – trends, developments and opportunities
This section provides an overview of trends and developments, state of play and future opportunities for Europe and European industry in the various identified application domains. Based on a concise review of existing analyses and studies, the results presented in this section provide a comprehensive picture on the possible directions in supply and demand and hence the potential of IMS-based integrated miniaturised systems.

3.2.1 Health and ageing
The main applications in the health and ageing domain are related to monitoring, assistance and treatment applications. The applications most relevant to IMS are:

- Miniaturised diagnostics or monitoring devices for professional use
- Miniaturised self-monitoring for personal use
- Devices that enable minimal invasive therapy
- Assisted living facilities (smart house technologies, robots assisting in household activity, environmental assistive devices)
- Devices that enable the self-treatment by patients
- Devices that support pharmacogenomics, gene therapy, genetic diagnosis, stem cell transplants
- Replacement applications (e.g. artificial body functions and limps).

*Trends and development in the health and ageing market*

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59 The listed applications do not contain software-related applications, such as databases of patient records, for two reasons. The first reason is that such applications are not new and belong to already existing product propositions. Another main reason is that evidence of cost reductions of ICT produces mixed results. The most frequently cited positive effects are generally attributed to reduced utilisation of health care services. More effective information sharing, such as rapid electronic delivery of hospital discharge reports or the use of computerised provider order-entry systems can reduce the uptake of laboratory and radiology tests to as much as 24% (OECD 2009). Other efficiency gains are reduction of administrative burden. However, in the OECD review of ICT in six OECD countries (Australia, Canada, the Netherlands, Spain, Sweden and the United States) GPs rarely reported a reduced workload as a result of using electronic medical records (OECD 2009).
The main applications in health and ageing can be captured by the term (electronic) medical devices. The expenditure on medical devices is sizeable, yet still a small part of total healthcare expenditure worldwide. This expenditure was estimated at US$ 5.7 trillion in 2009 (Eucomed 2010). The demand for medical devices is, however, rising fast. The global market potential – demand - for medical devices is huge, driven by demand and income developments. Since 2001 world sales of medical devices has doubled to US$ 210 billion in 2008. World sales have grown with an average annual rate of 6% (WHO 2010). Europe and the US account for the largest part of sales, with shares of 34% and 45% respectively, while Asia accounts for 18%. Within Asia, Japan is responsible for 10% (WHO 2010). These figures apply to medical devices; the electronic medical devices market to which IMS-based applications belong is a subset of the wider medical devices market.

Reasons for growth of the health and ageing market are related to longer life expectancy, more attention for health in general, but also to increased harmonisation of standards and norms in the healthcare market. Especially the latter have led to increasing possibilities for selling devices in more countries. In 1990, the European Union (EU) introduced in all its Member States an approach to medical device regulation based on mandatory “essential requirements” of safety, performance, and quality. Nevertheless, fragmentation in markets and in policies (including health insurance arrangements) make that Europe still consists very much of individual national markets. The advantages of one large home market, comparable to the United States, are still far off in Europe.

Growth in medical devices sales is not only demand but also supply driven. The main factor behind this is increased technological possibilities, in other words innovation. From 1980 to 2000 most hospitals adopted computerized axial tomography (CT) scanners and magnetic resonance imaging (MRI) units. New technologies have had a significant positive impact on health. According to Advamed, in the period 1980-2000 rapid technological progress resulted in a 15% decline in annual mortality, a 25% decline in disability rates, a 56% reduction in hospital days and a 3.2 year increase in life expectancy.60

From 2000 onwards, robotics, assisted devices and ICT integrated devices have made their way to healthcare. Many medical devices initially emerged not from clinical research but from technologies developed in other areas. According to the WHO, there is a growing need for smaller and less expensive systems. Miniaturisation will direct future medical devices. Another major trend affecting the future of health care is further convergence in technologies. This in particular holds for convergence in which the sharing of medical information between medical devices and IT applications and networks are

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http://www.advamed.org/MemberPortal/About/Industry/
key. Both the trend of miniaturization and of convergence are well reflected in the increase in demand for monitoring devices, both for personal and for professional use.

The need for affordable solutions is another driving factor. According to the WHO (2010) medical devices do not always provide cost-effective solutions. Uncertainty and high costs are factors that especially apply to the more complex devices. The growing demand for medical devices is one of the factors that significantly contribute to the rise in healthcare costs. Medical devices are estimated to account for 5 to 6% of total health expenditures in Europe, with even higher figures for Germany, and Belgium (8-9%). Around 80% of the total costs of medical devices relate to logistics, maintenance and training (WHO 2010). The price of the device is, although sizeable, a minor element in the total costs involved.

In order to be used in the best possible way, medical devices should be flexible and take the local context in which these are used into account. This especially applies to medical devices and their use in low(er) income countries. The wider context of the complete local healthcare systems, in which patients are being treated from investigation, diagnosis, treatment and management, follow-up, and rehabilitation, should be taken into account in order for medical devices to be effective (WHO 2010).

3.2.2 The medical devices industry
The medical devices industry employs around one million people in more than 27,000 medical device companies worldwide. The global top 30 medical device companies account for 89% of the global sales revenue with an estimated value of US$ 210 billion (WHO 2010). US companies dominate this list with 19 companies. In the list nine European companies are represented and two from Japan. The US, Europe and Japan are the main producers of high-tech medical devices. The major medical device manufacturers spend an average of 7.5% of their sales revenue on R&D (WHO 2010). However, the most active in R&D and most innovative companies are SMEs.

The main companies in Europe are Siemens, Covidien, Philips, B.Braun, Cardinal Health, Smith & Nephew, Alcon, Fresenius Medical Care and Dräger. These companies are located in Germany, the Netherlands, Ireland, the UK and Switzerland. Philips, Siemens and Covidien are concentrating on the high-tech medical equipment market. According to Eucomed, the sector in Europe employs around 500,000 people in about 11,000 companies, generating US$ 95 billion sales. European companies spend with 8% of their sales revenue more than average on R&D. European companies account for 12% of total patent filings, which is more than any other industrial sector in Europe (Eucomed 2010).
3.2.3 Sustainable mobility

The application domains in sustainable mobility can be divided in automotive applications and infrastructural applications. The automotive application domain includes:

- Advanced driver assistant systems (which can also be relevant for air and maritime transport)
- Applications that enable emission and (fossil) energy reductions in vehicles (and ships or airplanes). Examples are hybrid and/or electric vehicles; battery improvements
- Real-time multi-modal transport information systems for individual users to optimise transport mode and route selection.

The infrastructural application domain includes:

- Traffic management and control systems (electronic signs; signals; surveillance and monitoring)
- Automated road-user charging to optimise flow and reduce emissions (based on distance travelled, time of day, type or weight of vehicle, level of pollution)
- Logistics solutions to optimize the inter-change between long- and short distance travel.

The automotive applications are mostly provided by the automotive sector, whereas civil engineering companies and component providers provide infrastructural applications. However, both domains are increasingly linked to each other, with infrastructural applications being to a large extent dependent on automotive applications. For instance, road-user changes can be administered through traditional (electronic) toll-booth payment systems. However, toll can also be administered digitally through systems that can track the use of roads by a specific user. The same is true for traffic management systems. Navigation systems can link congestion data to monitoring services or authorities in order to obtain accurate traffic information.

The Intelligent Transport Systems (ITS) thus created apply information and communication technologies to vehicles or users. Computers, electronics, satellites and sensors are already playing an increasingly important role in our transport systems. The main innovation is the further integration of existing technologies to create new services. ITS as such are instruments that can be used for different purposes under different conditions. ITS can be applied in every transport mode (road, rail, air, water) and its services can be used by both passenger and freight transport (CCG 2007) The potential annual market demand for ITS equipment and services in France, Germany, Greece, Italy, the Netherlands, Spain, Sweden, and the UK alone is an estimated € 56.6 billion
by 2015 (CCG 2007). A large part of this demand is related to vehicle control systems (29%) and only a limited amount (3%) to electronic fee collection. The worldwide investment in electronic toll collection (ETC), however, is expected to grow to US$11 billion by 2015. Rapid growth is expected to continue well into the next decade, with the number of equipped lanes growing by an average of more than 10% per year (CCG 2007).

Real time multi modal transportation information systems can play a vital role in increasing logistics and supply chain efficiency. Costs of logistics, including transportation and warehousing, on average account for 10-15% of the final cost of the finished product. Globally, the logistics industry is worth an estimated €5.4 trillion, or almost 14% of global GDP (CEC 2007). Tracking and tracing of cargo in all modes and transport quality control can improve efficiency and optimize fleet utilization, through the use of transportation management systems.

Both ITS systems, ETC systems and real time multi modal transportation information systems can be beneficial for reducing congestion. Congestion reduction is one of the main issues in transport. Congestion costs the EU about 1% of its GDP, or around €100 billion each year. With around 300 million drivers in the EU today, and further expected increases in the distance travelled by road, it is expected that congestion costs will increase further by about 50% up to 2050 (CEC 2008). Ramp metering, traffic and incident detection and variable message sign systems are already being used across Europe.

Intelligent transport systems also provide opportunities for increasing safety. Since 1990, road fatalities in Europe have decreased from more than 70,000 fatalities, to around 40,000 in 2008. In total, there are approximately 1.7 million accidents on European roads annually. It is estimated that road accidents cost around €200 billion to the EU, equivalent to 2% of its GDP (CEC 2007). However, automotive solutions seem more viable to increase safety. These can be ranked in the application domain of Advanced Driver Assistance Systems (ADAS). Assisted and automated accident avoidance and vehicle control systems can help the drivers of cars, trucks and buses to avoid crashes and help keep them from running off the road (Lane Departure Warning System), but can also help maintain safe distances between vehicles and safe speeds approaching danger spots (Adaptive Cruise Control). Other applications can help improve visibility for drivers, especially at night and in bad weather. The possibilities for ADAS systems are widespread and not only limited to safety. Parking systems can help people park their car. More advanced ICT applications include the Driverless Car. Different car manufacturers and universities have tested the driverless car but it is not yet ready for production.

Navigation systems are also part of the application domain of Advanced Driver Assistance Systems. Navigation systems can provide benefits for reducing congestion and can contribute greatly to improving logistics, as these can
provide alternative routes, perhaps more effectively than traffic information systems.

Economically these applications can enhance demand for cars and can provide competitive advantage to vehicle manufactures. According to baseline projections of IEA (2009) the total undiscounted expenditure on vehicles and fuel from 2010 to 2050 will be about US$374 trillion, of which US$ 231 trillion on vehicles and US$ 144 trillion on fuels. This amounts to an average expenditure of nearly US$ 10 trillion per year. In a more emission reduction prone scenario, vehicle investment is set to increase by about 10% to 253 trillion US$ in 2050 (IEA 2009).

Decreasing fuel and energy consumption is vital in order to achieve sustainable mobility. ADAS systems provide means for achieving this. In terms of economic potential ADAS systems seem to provide major opportunities not only by enhancing the competitive position of European car manufacturers, but also because of the opportunities for reducing accidents and congestion and emissions.

An example is the start/stop systems. Many motor applications have high operating hours but variable loads. Even with the relatively flat efficiency curve of larger motors (between 50% and 125% load), there are still large gains to be made by adapting motor speed and torque to the required load. The largest benefit comes with pumps and fans in closed loops for which power consumption varies as a cubic power of their rotational speed. In traditional equipment the load adjustment is made by introducing artificial brakes (control valves, dampers, throttles, bypasses, etc.). In air conditioning systems, the temperature and flow control of pumps and fans can be achieved with variable speed drives reducing on/off cycles and providing a more stable indoor climate (Wade and Brunner 2011). According to estimates by the industry further fuel savings up to 30% could be possible as a result of improvements in conventional combustion engines up to 2030.

Hybrid electric vehicles and Electric vehicles (EVs) provide major opportunities for emission reductions and economic growth. Other opportunities in the automotive market include fuel cell vehicles. Hybrid concepts can also provide opportunities for maritime transport. The future for the automotive industry is shifting further towards the use of electric cars. The shift is especially supported by the decreasing cost of battery in terms of euro per KWh. For batteries the market potential is also huge, if the EVs are adopted on a large scale. McKinsey estimates that the global market can reach annual sales of US$ 60 billion annually (McKinsey 2010). With the decreasing cost of batteries, the price of electric cars will gradually decrease. In terms of market size, studies indicate that sales of electric and hybrid cars could constitute around 25% of the total global car market by 2020 (Hensley et al 2009). However, the successful introduction of EVs is much dependent on the provision of adequate infrastructure for recharging and/or changing of batteries.
3.2.4 The automotive industry

In 2007, the European automotive sector was responsible for 8.6 percent of value added in Europe (EU-27). Around 2.3 million people are employed in the sector in Europe. Worldwide market shares of the EU, US and Japan are declining in favour of China and India. In 2009 China became the world’s largest car producer with a 22% share in cars and a 25% share in commercial vehicles, followed by Japan and the US as second and third largest car producers worldwide. Japan was responsible for 14% of world car production and 8% of commercial vehicle production. The US is still the largest commercial vehicle producer with a market share of somewhat over 25%, but only 5% of world car production. In 2009 the EU as a whole had a market share of 29.3% of world car production and 9.5% in the production of commercial vehicles. In 2004 the share of Europe was 37% in cars and 29% in commercial vehicles worldwide (OICA 2010).

Europe exports more cars and parts than it imports. In 2007 automotive exports were €129.8 billion, while imports were less than half (€59.7 billion). Most exports are between member states. Outside the EU the main trading partners are the United States (around 25%), China (7%), the Russian Federation (7%), Turkey and Switzerland (5% and 4% respectively). Europe imports around 30% from the United States, 20% from Japan, 11% from South Korea, 10% from Turkey and 5% from China (Eurostat 2009).

European companies in the automotive sector spent more than twice the average manufacturing share of their value added on R&D. This share grew from 13% to almost 15% in the period 2000 to 2007. Globally, the US dominates in automotive R&D expenditure. Business expenditure on R&D in Europe is similar to the US. However, public spending on automotive R&D was around €1.7 billion, compared to €340 million in Europe. Public expenditure in Japan is limited to €77 million and private expenditure was less than half of EU spending in 2007. Public expenditure in automotive R&D was around €123 million in India and €213 million in China in 2007. Business expenditure on R&D in both India and China is limited compared to other regions (EAGAR 2010).

Although the industry is dominated by large OEM’s, about 50% of R&D investment comes from automotive suppliers. This also holds for the majority of patents. The value chain is highly integrated and strong co-operation for innovation exists between the OEM’s, systems providers (tier 1) and component providers (tier 2). In terms of competitive position, European OEM’s and systems and component providers have a leading position in ADAS systems worldwide. Major European systems and component providers are Bosch, Alpine, Siemens, Mannesmann, and Continental/VDO.

European automotive firms are leaders in some transitional drive-train and fuel technologies and are investing in ground-breaking technologies, such as battery-powered hybrid vehicles, electric vehicles and hydrogen. Japanese
companies lead the way in hybrid and electric vehicles. One interviewee from a leading European company pointed out that Europe lags about ten years behind in battery development vis-à-vis main competitors. As products are becoming increasingly complex from a technological point of view (e.g. the role of electronics), the industry is focusing increasingly on advanced, high technology products, which necessarily rely on a highly skilled workforce.

Navigation systems are important in many ways for sustainable mobility. Market leaders in this segment are Garmin (US) and Tomtom (NL), both in standalone and dash systems. Tomtom has a market share of 17% (Tomtom 2011). However, the market share for navigation systems in smartphones is growing fast; the incumbent navigation suppliers are active on the apps smartphone market, but face competition from other, sometimes free of charge, suppliers. Incumbents also try to move up-market with additional services. For instance, Tomtom is shifting towards even smarter applications such as traffic jam information based on mobile phone density and is moving to built-in systems in co-operation with leading automotive companies.

3.2.5 Sustainable production

Challenges related to sustainable production are related to cleaner production and recycling, more efficiency, but also to more effective production and better working environments. These challenges can be categorised into different application domains, as follows:

- Applications that enable more resource and energy efficient production processes (e.g. combined heat power; flexible and adaptive production; system optimization; intelligent and self-adaptive machinery; zero defect manufacturing)

- Applications that enable efficient production of (more) durable products using increased quality control (e.g. smart sensors and control systems)

- Applications that increase supply chain and logistics efficiency (e.g. RFID, wireless sensor networks, machine-to-machine communication)

- Applications for resource management and conservation (e.g. environmental monitoring equipment, sensing and control devices)

- Applications that enable waste treatment and recycling (e.g. smart sensor sorting; advanced density separation and recovery)

- Applications that enable better workplace environments and increased safety & health (e.g. new capabilities for robots and robot interfaces; measuring and sensing devices; human machine interaction).

Economic potential is difficult to establish for each application domain, as these technologies are used in a wide range of sectors and in a wide range of
products. Common factor is that these applications revolve around high-tech machinery and equipment. However, it is possible to say something about possible potential for society and the competitive position of the sector responsible for these application domains.

Energy and resource efficiency are two societal challenges. Currently industrial production accounts for one-third of global energy use and almost 40% of global CO2 emissions. The bulk of these emissions are related to the large primary materials industries, such as chemicals and petrochemicals, iron and steel, cement, pulp and paper, and aluminium. However, since 1978, the energy-intensity of the industry has declined from 3% in Australia to more than 60% in the Netherlands. In 1978 24.7 tons of oil equivalent (toe) was needed for the production of 1 million US$ added value, in 2008 this reduced to 14.6 toe per 1 million US$ added value in 22 OECD countries (Own calculations based on OECD energy balances). Significant energy efficiency potentials remain in all of these sectors and the use of metering and control devices can still improve energy-efficiency by 30%. Through metering and control systems it becomes possible to measure energy-consumption of production and to control the use of energy, for instance by shutting of machinery when there is no throughput. The benefit of lower energy-consumption is however, usually seen as only a by-product of automation.

The potential appears, however, biggest in the building or transport sectors, where energy intensity has increased (measures as tonnes of oil equivalent per inhabitant). Also, resource productivity in the EU (measured by GDP per resource use, €/kg) has improved 2.2% per annum in real terms over the past 10 years (CEC 2008). As prices for raw materials and energy are expected to rise, both resource and energy-efficiency are vital for EU manufacturing.

Modelling studies indicate that resource efficiency has scope to deliver substantial macro-economic benefits. For example, the RESA study found that a 20% improvement in resource efficiency in Austria could enhance GDP by 24% and employment by 2.4%. Modelling forecasts by the Aachen Foundation indicate that a 20% reduction in resource and energy use in Germany would create 1 million jobs, enhance GDP by 12% and improve public finances by €100 billion (Rayment 2009).

The potential impact economic for sustainable solutions impact is especially large for emerging markets. In India, other Asian countries, Africa and the Middle East, industrial development will accelerate. Industrial production in these three regions is expected, to increase over 250% by 2030 and almost 400% by 2050 compared to 2006 (IEA/OECD 2009). Large growth of production provides opportunities for sustainable production applications.

There is also a great market potential for recycling techniques. Much of the waste is sent for processing outside Europe and disassembled under inadequate conditions; almost 80% is buried in landfill or incinerated. Recycling can be importantly increased by smart sensor sorting and advanced
density separation and recovery techniques. The global market for environmental industries was estimated to be €1000 billion in 2005 and could reach €2200 billion in 2020 (CEC 2008). The EU is a strong player – 30% of world turnover and 50% of the world share of water and waste management (EACI 2009). Having a competitive advantage in sustainable production and recycling solutions can give European companies “first-mover” advantages in global competition (CEC 2010).

Workplace safety is another part of the sustainable production challenge. ILO estimates made in 2008 for 2003 indicate that about 358,000 fatal and 337 million non-fatal occupational accidents occurred in the world and that 1.95 million persons died from work-related diseases. The annual economic cost of major occupational accidents alone is estimated at US$5 billion (ILO 2010).

3.2.6 The machinery and equipment industry
The mechanical machinery and equipment sector is the largest with a share in total manufacturing value added of 11.6%, whereas the electrical machinery and equipment sector is responsible for 4.7% of manufacturing value added. Besides a high value added, the sector also employs a great deal of people. Both sectors have a total employment of 7.1 million people (Eurostat 2010). The sector contributes highly to European value added and as producer of so called key enabling technologies, is an important source of competitiveness for the European industry.

In 2010 the EU was the leading worldwide exporter of machinery and equipment and provided 37% of world exports of machinery and equipment (NACE 29). This share roughly increased from 34% in 2000, despite a decline of 19% in 2008/2009 due to the crisis. The export share of Japan and the US however decreased in favour of exports from China. The share of exports from China has grown since 2000 from just over 3% to almost 10% in 2006. The US share in 2006 was 18% (25% in 2000), while the share of Japan was 13% (17% in 2000). EU producers are less important in the electrical equipment part of export markets. In 2006, they accounted for just over 18% of total exports of the products concerned. Also for the electrical equipment the share of the US and Japan declined, while the share of exports of China increased. The US share was 13%, Japan 12.5% and the share of China was 16.5% (7.5% in 2000) (Eurostat, 2010).

The EU and Japan are leading in high tech machinery. The main competitors of the EU are the US and Japan and to a lesser extent Taiwan and Korea. Both Taiwan and Korea have a trade deficit with the EU for machinery (Ecorys 2011). The labour productivity of the machinery and equipment sector is much lower than productivity in Japan and the US. Japanese productivity is 60% higher, while US productivity is more than 90% higher. Nonetheless, Europe has performed better than the US on the global market (Ecorys 2011). Especially the US is losing ground in international competition. This is possibly related to outsourcing of manufacturing in general, but also because
of the strength of the US in ICT, which is also subject to outsourcing. Japan’s manufacturing base also suffers from outsourcing to nearby countries. The Chinese machine tool industry has become large in terms of its size. However, the focus is on medium-quality and low to medium-precision machining, but also the capacity for high-tech technology is increasing.

Expenditure on R&D in the EU is similar to the expenditure on R&D in the US and Japan, while in 1999 Europe was lagging behind, especially compared to Japan. In the EU R&D scoreboard European companies even outperform Japanese and US companies in terms of R&D expenditure. The R&D figures underestimate the real expenditure on R&D. Most machinery is custom built and requires a great deal of development and research. Product development is an integrated activity often in strong collaboration with customers and suppliers. Both upstream and downstream linkages provide new technologies to be integrated in machinery. There is continued focus on integrating design, computer-aided production, new material and new standards of precision emphasising links with R&D and universities and research centres.

In general, the strength of the European M&E sector lies in combining and integrating new advanced technologies, such as lasers, gear and drive technologies, sensors and optoelectronics, new materials with more “traditional” mechanical engineering technologies (Ecorys 2011). Over the years the intelligence and flexibility of machinery has increased. This allows for various opportunities for production technologies. European Engineering ingenuity and creativity are important aspects of this.

Another element in production technology is automation. The combination of ICT and high tech machinery is used for the automation of production processes. For automation of production, system engineering is an important topic. The ability to automate and control complex processes have made EU manufacturers highly demanded suppliers of complex and high tech machinery and equipment, but also for turnkey-plants. The EU is on the leading edge globally, next to Japanese firms and to a lesser extent US firms (Ecorys 2011). South Korea has become an important competitor in plant engineering, but their competitive advantage is based mostly on favourable financing conditions, instead of technology.

Europe has a strong position in high-tech performance machinery, such as lithography systems and machinery for the semiconductor industry. Europe is strong in some components, such as gear and drive technologies. The position is less outstanding in some advanced technologies supplied by upstream industries, such as optoelectronics and electronic sensors and control components. In these technologies Japan, South Korea and Taiwan have a leading position. However, the competitive position is changing and the EU and Asian countries are competing at the same level. Europe is the leading provider of energy efficient production technologies. 42% of energy savings can be attributed to investment in new machinery and equipment (Ecorys 2011).
3.2.7 Climate Change and Energy

In the Climate Change and Energy domain the following applications were selected:

- Wind energy applications
- Applications that enable smart metering, control and sensing
- (Renewable) energy transport optimising systems (e.g. smart grids)
- Intelligent (household) appliances, switches, control systems and sensors
- Applications that neutralize GHG / CO2 emissions (e.g. CCS)
- Solar energy applications (PV and CSP)
- Applications that enable improved storage of energy
- Applications for other renewable energy sources (e.g. energy scavenging).

Climate change poses a number of threats for society and the economy at large. Climate change offers opportunities for new technologies including emission abatement and clean(er) energy. The impact of emission abatement on GDP is likely to grow over time and could become substantial by 2050, with estimates ranging from 4% to 7% of GDP (OECD 2009). The United Nations Framework Convention on Climate Change (UNFCCC) estimates that an additional $200 billion in global investment and financial flows will be required annually by 2030 just to bring GHG emissions back to current levels (Newell 2009).

The International Energy Agency (IEA) has created several emission abatement scenarios, the baseline scenario estimates that 270 trillion US$ is needed during the period 2007-2050, most of which (US$ 240 trillion) is equipment, including vehicles, electric appliances, and plants in heavy industry. Investments from 2030 to 2050 are highest, as increased income stimulates demand for cars and other consumer durables (IEA 2009).

Further reductions of emissions requires additional investment, of US$ 46 trillion, but these costs are offset by cumulative fuel savings of US$ 112 trillion. Additional investment needs are dominated by the transport sector (50% of the total). Buildings account for 26% of the total additional investment, power generation for another 20%, and industry for 4% (IEA 2009). In these scenario’s Carbon capture and Storage is important. Other calculations show that for Europe alone achieving a target beyond 20% requires additional investments amounting to at least 2% of GDP each year until 2020 (Schleicher 2011).

In 2007 countries spent about US$ 1 trillion globally each year on R&D in clean(er) energy, of which around 70% is funded by industry and 30% by
government. 95% of these investments occur in the OECD countries, Russia, and China, with the G8 spending 80% of the total R&D expenditure (Newell 2009).

According to Schleicher (2011) world investment in clean energy is dominated by the EU followed by China and the US. The EU spent US$ 41 billion on clean energy, with the UK and Spain as main investors. China spent around US$ 34 billion, compared to US$ 18.5 billion by the US. Although by 2009 EU expenditures on clean energy exceeded those of China, China expanded its investments by about 30% in 2010 (Bloomberg New Energy Finance). China now represents about one fifth of total world demand for clean energy investments (Schleicher 2011). In 2009 investments for wind energy and solar energy were particularly high.

Wind energy is the second-largest contributor to renewable electricity today after hydro energy. The average newly installed grid-connected turbine has a rated capacity of about 1.6 MW. It extracts energy from the wind by means of a horizontal rotor, upwind of the tower, with blades that can be pitched to control the rotational speed of a shaft linked via a gearbox to a generator. Control systems can enhance efficiency, as these can respond to changes in wind conditions. Efficiency can further be optimised through improvement of transmission technology and enabling technologies including smart grids that will enhance the overall flexibility of power systems and allow for their operation with large shares of wind power. Offshore wind industry is developing, particularly in Europe, and a specific offshore supply chain is emerging. Wind energy has Europe has taken the lead in wind energy and has consolidated its position as global market leader. The EU R&D scoreboard records 13 EU companies in wind and solar energy, with Vestas Wind from Denmark as the EU leader in wind energy. The main company outside the EU in wind energy is from Norway.

The EU also has several large solar energy companies, most notably in Germany. The importance of solar energy as an alternative sustainable energy source has increased over the years. One problem with solar energy is its high cost of production, which is about twice as much as the cost of conventional energy generation. However, with improvements in photovoltaic technology, costs are expected to decrease and solar power will become more and more attractive. Photovoltaic module costs have decreased in the past with a learning rate of between 15% and 22%. System prices fell by 40% in 2008/09 alone (IEA, 2010a). The installed worldwide capacity of PV has been growing on average by 40% per year for almost 10 years, and with incentive schemes in several countries encouraging PV deployment, this trend is expected to continue. The increase will induce lower costs. The “SET for 2020” study (www.setfor2020.eu) carried out by EPIA (European Photovoltaic Industry Association) and A.T. Kearney outlines that, provided some boundary conditions are met, PV could supply up to 12% of the electricity demand in
Europe by 2020, thus representing 390 GW of installed capacity and 460 TWh of electricity generation.

Photovoltaic (PV) cells are semiconductor devices that convert solar energy into direct-current electricity. Photovoltaic cells are interconnected to form PV modules with a power capacity of up to several hundred watts. Photovoltaic modules are then combined to form PV systems. Photovoltaic systems can be used for on-grid and off-grid applications. They are highly modular, i.e. modules can be linked together to provide power in a range of from a few watts to several megawatts.

Photovoltaic technologies can be applied in a very diverse range of applications, including in residential systems, commercial systems, utility-scale systems and off-grid applications of varying sizes. Different PV technologies may suit different uses. Off-grid applications offer the potential for the electrification of remote areas. To summarise, both solar energy and wind energy can benefit greatly from advances in nano-electronics and integrated miniaturised systems.

Renewable energy sources are dependent on the external conditions for the provision of energy. The increased use of renewable sources requires greater power system flexibility than is the case with most conventional sources. Such flexibility is needed in order to rapidly supplement periods of low output and to manage production peaks. Flexibility can be achieved by smart grid and energy storage technologies.

Smart grids are a broad range of solutions that optimize the energy value chain. A smart grid uses digital technology to improve reliability, security, and efficiency of the electric system: from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources.

Smart grids have the potential to address many future electricity network challenges. Most important is to reduce transmission and distribution losses that account for 9% of all energy generation worldwide, and vary much more between regions (IEA 2009). The US Energy Information Administration calculated that electricity lost in transmission and distribution cost the economy US$ 49 billion per year.

Smart grid technologies show strong potential to optimise asset utilisation by shifting peak load to off peak times, thereby decoupling electricity growth from peak load growth. This increases flexibility to enable the balancing of variable generation and demand, better management of peak loads. Furthermore,

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smart grids can offer direct feedback to consumers concerning energy usage, encouraging energy efficiency. Finally, smart grids can provide the infrastructure needed for the large scale adoption of electric vehicles. This is referred to as grid to vehicle (G2V) (IEA 2011). As mentioned above, smart grids increase the efficiency of solar and wind power, thus stimulating the use of these technologies. The IEA estimates that smart grids can lead to emission reductions of 0.7 gigatonnes (Gt) to 2.1 Gt of CO$_2$ by 2050, which represents around 4% of the reductions needed to halve energy-related CO$_2$ emissions by 2050 (IEA 2011).

The International Energy Agency estimates that over $6 trillion needs to be invested in transmission and distribution by 2030. A total of 5,087 GW of generating capacity will be built worldwide by 2030, with 2,700 GW of that in developing countries (1,100 GW in China alone). But technical work is still required, especially to demonstrate such grids at system scale. Currently many countries are undertaking pilot projects. Italy was first with the Telegestore project, launched in 2001 by ENEL Distribuzione SpA. The project has resulted in fewer service interruptions, and its €2.1 billion investment has led to actual cost savings of more than €500 million per year. Also other European countries have started programs for smart grids. Spending on smart grids projects is relatively high in the EU. The US agreed to invest around US$ 435 million in demonstration projects. Also China has planned to invest US$ 96 billion in smart grids by 2020 (IEA 2011). European and US firms dominate the world market. European companies, such as Alstom, Schneider, Siemens, KEMA are among the global leaders in smart grid technology.

Storage applications, such as electrochemical capacitors and batteries provide the network with additional flexibility. Moreover, storage device can also help in increasing the value of the use of renewable energy sources. Having the capability to store energy from renewable sources will ensure that these sources become competitive. Storage application can benefit from advances in nano-electronics, but the economic potential and societal impact are difficult to assess.

Carbon capture and storage (CCS) are seen by the IEA and UNIDO (2011) as the only technology, with the exception of energy-efficiency measures, that allows for profound reductions in CO$_2$ emissions in energy intensive sectors, but so far has received little attention (IEA and UNIDO 2011). Commercial-size CCS projects have been limited to a few industrial applications. Some CCS technologies have already come to maturity, such as transportation of CO$_2$ in pipelines and several storage options. CCS technologies rely on the removal of CO$_2$ from industrial processes, resulting in so-called high-purity CO$_2$ sources. Many other applications of CCS in industry – for example for boilers, turbines, iron and steel furnaces, direct iron reduction processes and cement kilns – require additional CO$_2$ separation technologies to concentrate dilute streams of CO$_2$ to a level that enables economic transportation and storage (IAE and
This requires industrial process modifications. However, it is not clear how these technologies benefit from integrated miniaturised systems.

CCS could reduce CO₂ emissions by up to 4.0 (Gt) annually by 2050 in industrial applications, accounting for about 9% of the reductions needed to halve energy-related CO₂ emissions by 2050. To achieve this target, 20% to 40% of all facilities need to be equipped with CCS by 2050. To achieve this level of CCS implementation in industrial applications, it is estimated that additional investments of US$ 882 billion are required by 2050, over 75% of this in non-OECD member countries. Total cumulative additional costs, including additional investments, operation, transport and storage, would reach about US$ 3 trillion by 2050 (IEA and UNIDO 2011).

Finally, reduction of residential energy consumption is a vital aspect in climate change policy. More and more of those appliances are becoming “grid-aware” and gaining the ability to monitor and report their own usage and to increase or decrease their electricity usage by remote command. Smart appliances are mentioned as the second best option mentioned by consumers they can do themselves to reduce GHG emissions, while recycling scores highest (McKinsey 2010).

Figure 7 Division of energy saving potential in the residential sector

Possibilities for residential energy savings are shown in the figure above. Heating and Cooling account for most savings within the residential area. Energy reductions for lightning and electronic appliances are limited compared to these applications.

However, out of the total required investments in order to achieve emission reduction targets appliances do account around 3 US$ trillion investments, or
23% of total investment needed, which means that smart appliances have great economic potential.

Figure 8 Investment in energy-efficiency in the residential sector

![Investment in energy-efficiency in the residential sector](image)

Source IEA (2009)

In order to grasp the full potential of smart appliances, appliances need to be able to communicate with other devices and become “grid aware”. Smart grids are therefore essential, but also smart meters that provide the interaction between home appliances and the grid. Both provide the two-way communication between producers and consumers. The smart meters allow consumers to monitor their energy consumption and take action accordingly. Through communication between smart meters and grids variable pricing strategies can be adopted, allowing more efficient use of electricity.

For many appliances production and development has shifted to Asian countries, which is especially the case for radio, computer and television equipment. European companies still have a competitive position in washing and drying machines. Bosch, Miele and AEG are examples in this case. Therefore it is questionable to what extent European companies are able to profit from developments in smart appliances.

Companies that produce products related to climate change fall mainly under the machinery and equipment sector\(^62\), which has already been discussed. There, it was discussed that for energy efficiency, European companies have a competitive advantage compared to other regions. Private R&D spending on energy efficiency also highlights this fact. Total global private low-carbon energy RD&D investments totalled nearly 15 billion US$ in 2009, with companies headquartered in Europe, the Middle East and Africa accounting for over half of this (IEA 2009).

\(^62\) In our definition also electronic equipment and components are included
3.3 Application domains – future potential as perceived by industry and the research community

This section discusses the opportunities and future potential for each of the applications as perceived by European companies, universities and research institutes. An important part of this section is based on the results of an online survey. In-depth insights were also obtained from interviews.

The survey questionnaire was sent out to 1,938 organisations consisting of European companies, universities and research institutes. 314 organisations filled in the survey, of which 263 completed the full survey. Respondents were spread across all European countries. A detailed description of the survey and respondent characteristics can be found in Appendix B. Survey respondents were asked to select one or more application domains based on their current and/or future organizational involvement in the use and/or production of applications, but also on the basis of their broader expertise, knowledge and perception of the competitive and technological playing field in IMS. The respondents were subsequently asked to assess and rank the applications within each application domain on five main aspects:

- **Impact on society**, i.e. the potential contribution of each of the listed applications to solving one or more of the grand challenges
- **Impact on economic growth and competitiveness**, i.e. the growth opportunities for European industry and the opportunities to strengthen their competitive position
- **Current competitive position of the European industry**, i.e. current performance and position compared to competitors in the listed applications
- **Systemic complexity of the listed applications**, i.e. complexity in terms of manufacturability of the application, challenges in reliability but also the infrastructure to realise IMS applications,
- **User acceptance risk**, i.e. the risk of non-acceptance of applications by end customers/consumers.

In terms of being active in the domain of more of the four grand challenges, the respondents were rather evenly distributed. Most respondents were active in the field of climate change (58%) and sustainable production (49%), followed by health & ageing (45%) and sustainable mobility (44%). Asked about future opportunities for their organization in IMS based applications, 28% of all respondents stated that sustainable production offered most opportunities, followed by health & ageing, climate change and sustainable mobility (respectively 25%, 20% and 15% of all respondents).

Applications score high, if:
Their contribution in solving grand challenges is perceived as high.

They are judged to have high potential in terms of strengthening future economic growth and competitiveness.

They are perceived to contribute strongly to the competitive position of Europe.

Systemic complexity is perceived as average or high (as an implicit measure of premium product potential and barrier to easy imitation).

Public acceptance risks are judged as low.

3.3.1 Overview of the main survey scores for health and ageing-related applications

Miniaturised devices for self-monitoring and professional diagnostics and monitoring score highest in potential contribution to solving societal health and ageing challenges, closely followed by devices that enable minimal invasive therapy. Devices for personal use are expected to provide most economic potential, together with assisted living facilities. According to the respondents, Europe has a favourable competitive position compared to other regions in devices for professional use. This also holds for devices for personal use and the devices that enable self treatment. Europe’s position is weakest in replacement applications. On systemic complexity professional devices for monitoring and diagnostics score lowest (meaning that complexity is not, much an issue). This is also true for devices for personal use, followed by devices that enable minimal invasive therapy and assisted living facilities. Systemic complexity is highest for devices that enable self treatment. For these applications there is also a high public acceptance risk. For monitoring and diagnostic devices for personal and professional use and devices that enable minimal invasive therapy this risk is little.

3.3.2 Overview of the main survey scores for climate change-related applications

In terms of potential of addressing and solving climate change challenges, applications that neutralise emissions, transport optimising systems, and smart metering applications score highest. According to respondents wind energy applications score highest in terms of current competitive position, but rank behind smart metering; intelligent household appliances, switches and sensors; applications that neutralize GHG emissions; and renewable energy transport optimising systems when it comes to future economic potential. Other renewable energy applications, solar energy and storage applications score lower in terms of perceived economic potential.

Europe is thought to have a good competitive position in wind energy, compared to other regions. (Renewable) energy transport optimising systems,
such as smart grids, score high on the competitive position, as well as solar energy applications. Intelligent (household) appliances score quite low on the competitive position.

Systemic complexity is perceived lowest for solar and wind energy applications and highest for storage applications and energy transport optimising systems. Storage, wind and solar applications have the lowest user acceptance risk, but scores for each application area are not very different.

3.3.3 Overview of the main survey scores for sustainable production-related applications

Applications that enable more resource and energy efficient production processes score highest on all main five aspects, followed by applications that enable efficient production of (more) durable goods through increased quality control. The latter applications score high on the ability to solve sustainable production issues and the potential for economic growth. Applications that increase supply chain management also score high in terms of the ability to solve sustainable production issues and economic growth.

According to respondents, Europe has a favourable position in waste treatment and recycling applications, but also in applications that enable more resource and energy efficient production processes and applications that enable better workplace environments. Europe’s position is least favourable in supply chain applications. Recycling and waste treatment applications are considered to be most complex. Perceived as least complex are applications that increase supply chain and logistics efficiency and applications for resource management and conservation (e.g. environmental monitoring equipment, sensing and control devices). The various applications score similar on user acceptance risk, except for applications that enable better workplace environments (low score).

3.3.4 Overview of the main survey scores for sustainable mobility-related applications

Advanced driver assistant systems (ADAS) score highest on the ability to solve sustainable mobility issues, economic potential and current competitive position. It scores, however, lower on systemic complexity and user acceptance. Real-time multi-model transport information systems for individual users that enable transport optimisation and route selection applications show the highest scores on average.

Applications that enable emission and (fossil) energy reductions in vehicles and ships (hybrid and/or electric; battery improvements) score quite high on the ability to solve sustainable mobility issues and economic potential, but rather low on the current competitive position and systemic complexity and user acceptance. Automated road-user charging applications scores quite high on the ability to solve the grand challenge of sustainable mobility, on future
economic potential and on current competitive position, but low on systemic complexity and especially low on the risks of user acceptance.

3.4 Application domains – barriers and challenges as perceived by industry and the research community

This section discusses the main barriers and challenges as perceived by European companies, universities and research institutes. An important part of this section is based on the results of an online survey. In-depth insights were also obtained from interviews.

Survey respondents were asked to identify in which stage of the innovation process they saw the biggest challenges. Almost 29% of all respondents indicated that the biggest challenge is in applied research. 24% of the respondents saw the main challenges in the demonstration and pilot phase. Especially the latter implies an important challenge for public innovation support in Europe, which is still heavily concentrated on support for Research and Development. In-depth interviews supported this inference. In competing countries outside Europe, different approaches to support appear to be taken, leading to a further sliding of the global competitive playing field with a potential negative impact for Europe. In various application domains the need for active support in demonstration and piloting – “prototypes at work” were voiced. In-depth interview results in this project support and emphasise this need.

In the RTDI chain, the innovation part with pilots and demonstration as important stages gets the lowest level of public support, being seen as competitive rather than pre-competitive, and following prevailing European State Aid rules. However, the capital needs at this stage of the innovation cycle are particularly high. The ‘valley of death’ which in Europe takes a particular toll in the demise of young promising companies and the lack of innovation funding at the later stage of the innovation cycle appear to highly related. The call for adequate remediating action is urgent, as the final report of the High Level expert Group Key Enabling Technologies states. Interviews in this project support this view.

Basic research scores lowest in terms of challenges ahead. Although not part of the survey, this low score might well relate to the strengths of European academic research in the IMS-domain. Respondents also do not expect strong challenges in the production stage. Most challenges are expected in applied research, followed by demonstration and piloting (2nd), and development (3rd).

| Figure 9 Most important challenges for IMS-based applications |
|-----------------------------|----------------|----------------|----------------|----------------|
|                             | CC | HA | SM | SP | Total share | Rank |
| Most important challenges   |    |    |    |    |             |      |


According to the survey respondents the main barriers for the realisation of IMS-based applications are lack of public funding, inadequate business models and lack of private funding, followed by economic risk. Lack of cooperation with the nano-electronics sector also scores quite high, especially in sustainable production. In health and ageing this barrier, however, does not appear to play a significant role. Other important barriers include the lack of qualified people and skills, in particular in the climate change, sustainable production and health and ageing domain. Public acceptance is seen as an issue, although less important. Lack of infrastructure is only in the health and ageing domain seen as an issue. Lack of research or ethical issues do not play a role whatsoever, according to the survey respondent.

Figure 10 Most important barriers for IMS-based applications
When it comes to the most important barrier or challenge, small differences in the ranking order apply between the applications domains of the four grand challenges. In all four application domains lack of public funding, inadequate business models and lack of private funding are rated most important, out of twelve barrier and opportunity categories. For applications in the climate change and the sustainable mobility domain lack of public funding is seen as most important barrier; in sustainable production lack of private funding is seen as prime. In health and ageing inadequate business models were perceived as most important barrier.

3.5 Selection of key applications

An important goal of the review, the survey and the interviews was to systematically compare the opportunities and challenges for the various application domains and applications, as to enable a balanced selection of most promising application domains and applications. The survey results enable a first final selection of most promising applications for Europe.

Figure 11 The ten most promising IMS applications based on survey results

<table>
<thead>
<tr>
<th>GC</th>
<th>Application</th>
<th>Ability to solve</th>
<th>Economic potential</th>
<th>Competitive position</th>
<th>Systemic complexity</th>
<th>Average score</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>Applications that enable more resource and energy efficient production processes (e.g. combined heat power; flexible and adaptive production; system optimization; intelligent and self-adaptive machinery; zero defect manufacturing)</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>SM</td>
<td>Advanced driver assistant systems (maritime, road, air)</td>
<td>14</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>SP</td>
<td>Applications that enable efficient production of (more) durable products using increased quality control (e.g. smart sensors and control systems)</td>
<td>2</td>
<td>6</td>
<td>13</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>HA</td>
<td>Miniaturised self-monitoring for personal use</td>
<td>3</td>
<td>3</td>
<td>17</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>SM</td>
<td>Applications that enable emission and (fossil) energy reductions in vehicles and ships (hybrid and/or electric; battery improvements)</td>
<td>13</td>
<td>2</td>
<td>20</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>CC</td>
<td>Applications that enable smart metering, control and sensing</td>
<td>6</td>
<td>4</td>
<td>16</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>HA</td>
<td>Miniaturised diagnostics or monitoring devices for professional use</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>21</td>
<td>7</td>
</tr>
</tbody>
</table>
The above table shows the ten applications with the highest average scores. In selecting these ten applications no special weighting was attached to either the grand challenges *per se*, the ability to contribute to solving one or more grand challenges or the future economic potential of the application. Such a weighting is possible. However, a weighting easily could create an undesired bias, as these results are mostly based on a sample only. As highlighted in the introduction of this section, the respondents were quite evenly spread over the grand challenges, which makes the selection of ten most promising applications balanced.

In assessing the survey results, the differences in answers between those who use and/or apply and those who do not already use or apply integrated miniaturised systems in their products appeared to be marginal. For respondents that already use integrated miniaturised systems scores were on average lower, but at the same time the variance in answers appeared higher. However, since one may be more inclined to value the answers given by those who do use integrated miniaturised systems higher, as they might be more knowledgeable about potential impacts, the final selection was primarily based on responses from stakeholders who already work with, use or apply integrated miniaturised systems.

### 3.5.1 Choosing three most promising applications

Based on the survey ranking, the interviews and the review of opportunities and challenges in the application domains, a further selection of three most promising applications for Europe was made. The three-out-of-ten final choice was concluded by the full research team and resulted after extensive discussion. The applications

- score high on potential contribution to solving one or more grand challenges
- offer ample growth opportunities for European industry, adding to already strengths and market position, and
- bear sufficient RTDI challenges to be targeted by EU public support programming in the period 2014-2020.

Apart from the three main criteria for selection (the basic rationale), more specific arguments for selection can be advanced. The specific rationale for...
selecting each of the applications is described below. The three selected most promising applications are:

- Applications that enable smart metering, control and sensing in combination with smart grids (Climate Change)
- Miniaturised self-monitoring for personal use and miniaturised diagnostics for monitoring devices for professional use (Health and Ageing)
- Advanced driver assistant systems in combination with real-time multi-modal transport information systems for individual users to optimise transport mode and route selection (Sustainable Mobility).

3.5.2 Description and underlying rationale

1. Applications that enable smart metering, control and sensing in combination with smart grids (Climate Change)

Smart metering applications and (renewable) energy transport optimising systems both show high scores in the climate change domain. Smart metering scores high on the ability to solve challenges and on economic potential, but less high on current competitive position. Moreover, smart metering is rated higher by respondents that use or apply integrated miniaturised systems than by those who do not use integrated miniaturised systems.

In the review, it was discussed that smart grids and smart meters are important enablers of energy efficiency, not only as they reduce inefficiency directly because of reduced transmission losses, reduction of peak demand and because of better insight in energy-consumption, which stimulates energy-efficiency.

Smart grids and smart meters are essentially communication systems for energy applications and both enable two way communication. Together smart grids and smart meters in industry and households provide an infrastructure that can act as a strong enabler for a green economy. These systems are vital for the adoption of renewable energy sources and energy storage and provide the necessary infrastructure for the adoption of electric vehicles. Smart meters can act as hub between the network and domestic smart appliances enabled by wireless communication.

Moreover, the review results show that smart metering, control and sensing are also important in the sustainable production domain, especially in systems for energy-efficiency in production areas. The same holds true for new concepts in flexible manufacturing.

Investments in new transmission equipment are huge. The widescale adoption of smart meters and smart grids lead to costs savings for households and industry by increasing energy-efficiency and optimal tariff selection, but also reduced cost for maintaining peak load production capacity. These systems
enable variable electricity tariff structures and further possibilities for increased competition between energy providers and possibly lower prices. Finally, these systems provide a reliable infrastructure and lead to less blackouts.

Although the survey would indicate that Europe currently has a less favourable competitive position in smart meters, it does have a strong position in production technology and smart grids. Interviews suggest that the US and the EU are competing at the same level, while Asia is lagging behind. The EU has some strong players, such as Siemens, ABB and Alstom. Standardisation for the smart grid infrastructure is further developed in the EU, which stimulates wide scale adoption. In the telecommunications infrastructure needed for smart grids, the EU is leading. The networks in the EU tend to be more advanced than other regions. This aspect is reflected in the number of blackouts that is lower in the EU.

According to interviews the technological barriers for smart grids are limited. Developments are very rapid.

2. Miniaturised self-monitoring for personal use and miniaturised diagnostics or monitoring devices for professional use (Health and Ageing)

Health and ageing applications with high overall scores are miniaturised diagnostic and monitoring devices for personal and professional use. Both score high on the ability to contribute to solving the grand challenge and on economic potential, but according to respondents the position of European industry is not yet very strong.

Miniaturised monitoring and diagnostic instruments fulfil the need for cheaper and smaller medical devices as was discussed above. Examples are external defibrillation devices, devices for cardiac arrests that automatically send a signal to emergency services, reveal type products, a small inserted device that diagnoses over specific health problems over a long time period. Integrating different functions is important in order to be able to provide better diagnosis and to determine appropriate action: call emergency services, when to start recording data, whether to send the data directly or store data locally. These devices often do not reduce the need for more large scale devices within hospitals, as more adequate measurement is often needed. Devices are therefore not a replacement of more complex products, but complementary.

Miniaturised and integrated medical devices can be used for prevention. Hospitalisation usually occurs after a crisis. If adequate measures can be taken beforehand, hospitalisation can be reduced. Devices can gather enormous amounts of data, which can be vital for improving medical research. Moreover, implanted devices can prevent user interference with data, enhancing the
reliability of medical research. Finally, these devices can also be used to
administer treatment and are able to enhance response times of emergency
services.

Due to ageing of European societies there is a growing market potential.
Moreover, these devices less hospitalisation means lower health costs. Less
personal monitoring is needed, which also stimulates independent living.

Main companies in the medical devices sector are in the US and the EU.
According to the survey results, the EU is following compared to the US. One
of the main challenges is to study the cost-effectiveness of medical devices.

3. Advanced driver assistant systems in combination with real-time multi-modal transport information systems for individual users to optimise transport mode and route selection (Sustainable Mobility)

Advanced driver assistant systems and applications that enable emission and
(fossil) energy reductions in vehicles are seen as most promising applications
in the sustainable domain. Advanced driver assistant systems score high on
current competitive position, but do not score very high economic potential
nor on the ability to solve the sustainable mobility grand challenge. The
reverse is true for applications that enable emission and (fossil) energy
reductions in vehicles. As shown in the overview of the applications, ADAS
systems can be used for many goals related to the grand challenge and can be
applied in both electric and conventional vehicles.

Integration between these systems and the communication between these
systems in other vehicles can greatly enhance driving. Miniaturisation and
integration is important, as space is a scarce resource in vehicles.

ADAS systems enhance vehicle safety and reduce energy-consumption by
optimising driving conditions. Communication between systems and between
vehicles can increase possibilities for safety and optimise traffic. For instance,
when one car notices the wheels slip because of oil on the road, other vehicles
can be notified in order to prepare their systems or can be advised on a
different route. Another example is the use of sensors and communication
systems to make it possible for a manually driven truck to be followed by
guided trucks. This is called platooning. This can enhance fuel efficiency and
increased efficiency of road usage.

ADAS systems and especially navigation systems that are able to communicate
with other vehicle or are able to send and receive data can provide
decentralised traffic management systems. This provides optimal traffic
management, as congestion, infrastructure works and accidents can be
communicated directly to vehicles so alternative routes can be optimally
chosen, in case of emergency, traffic management can directly influence route
selection. Current traffic management systems are unable to provide personalised advice for route selection. Better route selection also leads to lower fuel consumption.

Next to the direct economic impact in terms of sales, ADAS systems provide increased potential for differentiation for car manufacturers.

Moreover, ADAS systems have an indirect economic impact through reducing congestion and accidents and cost savings because of lower fuel consumption. Moreover, leading the way in ADAS systems can also enhance vehicle sales and offers possibilities for intelligent transport and payment systems (insurance, taxes, toll), meaning also decreased costs for centralised traffic management systems. Furthermore, cost savings in road infrastructure are possible, because of more efficient use.

According to the survey and interview results, the EU is leading in innovation, especially in ADAS systems. The EU is also very competitive in the development and production of sensors, actuators and radar technologies. Camera’s and optical sensors are usually produced in high volumes outside the EU.

Studies about the user response to automated vehicle solutions are needed in order to assess safety. Pilot projects are vital to assess the real potential. Research topics are related to sensor fusion, scene recognition and systems architecture (centralised vs. decentralised intelligence. One of the main questions is how to include the driver in the system). Decentralised traffic management systems through communicating navigation systems are thought to provide a lack of control to authorities. Pilots can prove whether or not this is the case.

3.6 Conclusions

Based on identified grand societal challenges and their impact on society, the first spotlight in the study was set on identifying application domains of high relevance for both, the handling of the grand societal challenges and the future trends in integrated miniaturised systems.

Europe is strong in several domains, such as in the high-tech medical devices field; in automotive (ADAS systems), drive-train and fuel technologies and battery-powered hybrid vehicles, electric vehicles and hydrogen; in combining and integrating new advanced technologies such as lasers, gear and drive technologies, sensors and optoelectronics in the M&E industry.

Based on empirical inquiries the study’s scoring system was able to show that in particular the following application domains meet the requirements. These application domains are:

- Applications that enable smart metering, control and sensing in combination with smart grids (Climate Change)
- Miniaturised self-monitoring for personal use and miniaturised diagnostics or monitoring devices for professional use (Healthy Ageing)

- Advanced driver assistant systems in combination with real-time multimodal transport information systems for individual users to optimise transport mode and route selection. (Sustainable Mobility).

These application domains show a high ability to contribute to the solution of problems initiated by the grand societal challenges. They also show high economic potential for European players. The competitive position of European players acting in these application domains is fairly strong as is the systemic complexity of technological and economic approach.

The empirical study clearly indicated that all three application domains are challenged by high demands on applied research and the developments of demonstration and pilot installations. That makes quite sure that the majority of the experts consulted do not see a need for fundamental research results but are more concerned on those research results that reduce time to market and enhance the usability of the applications generated in the application domains.
4. Changing business models and IMS industries

This chapter identifies the main strategies and business development trends in the micro/nano-electronics and IMS-using industries, with a specific focus on Europe and European industry. It describes how changes in market dynamics as well as technological developments have altered - and continue to alter – business strategies and business models. Based on this analysis, specific future needs for European industry are identified to maintain competitive edge and stay at the forefront of developments.

4.1 Dynamics in the micro- and nano-electronics industry: Europe in a global context

In order to assess business strategies of the European industry involved in the development and production of integrated miniaturized systems, their relevance in a global context of competitors should be defined. This section focuses on the micro- and nano-electronics sector as an important representative of the industry involved in the development and production of integrated miniaturised systems.

4.1.1 The micro- and nano-electronics industry and its importance for Europe

Micro- and nano-electronics is a global industry with strategic importance for Europe, not only because of major European players being involved in its R&D, design and – still, albeit less – manufacturing, but also because of the importance of microelectronics for various other key industries in Europe. This applies to various, mostly downstream industries, such as automotive/mobility/transport, communication/telecoms and consumer electronics, security, medical/healthcare, machinery and equipment (including industrial automation), energy (solar, wind turbine, energy conservation) and the environmental industry, and other industries. But it applies also to upstream industries, such as the photonics, microscopy/optical lenses and metrology supplying industry.

Today the micro- and nano-electronics industry (defined as materials, equipment and semiconductors) comprises approximately 500 companies in Europe employing about 200,000 people and about 1 million indirect jobs, excluding the electronics systems and services industry (HLeG KETs, 2011: 15).

The importance of the micro- and nano-electronics industry for Europe is undisputed. According to SEMI (2011) the microelectronics and software industries together nowadays "spearhead 90% of innovations on growth..."
markets like healthcare, energy and the automotive industry”. This applies, for instance, to the role of electronics in improving engine performance and improving passenger safety for instance, where electronics in 2000 accounted for an average 22% of the price of a car, a figure that had risen to 35% by 2010 and is likely to rise to 45% in 2015.

The market potential for micro- and nano-electronics worldwide is estimated at US$300 bn by 2015, up from US$ 250 bn (2006-08 average), with an expected compound annual growth rate of about 13% (HLeG KETs, 2011). In Europe semiconductors accounted for 30 bn US$ in 2009 (HLeG Micro/Nanoelectroncs Sherpa Team report, November 2010).

4.1.2 Market and business strategy developments in the semiconductor industry

In 2010, Europe was the third largest semiconductor producer worldwide, with 10% of total global output, 14% of total global sales and 20% of the global design activities market. Asia dominated the global semiconductor market with about 70% of total production and 55% of total sales, and 30% semiconductor design activities (SEMI, 2011). 80% of the world’s new semiconductor plants are planned to be built in Asia (IC Insights, February 2011). Measured in terms of global sales, STMicroelectronics is the only European semiconductor company still within the top 10 (see Table 12).

Until the early 2000’s, Europe still had three of the top-ten semiconductor manufacturers in the world (i.e. STMicroelectronics, Siemens and Philips) (ICT Man, 2011). During the 1990’s, semiconductor companies had already started building fabs in Asia targeting cost reductions. A large part of the manufacturing activities remained in Europe though. The semiconductor industry, however, faced major changes in the beginning of the 21st century. The ICT-bubble burst set the stage for a dramatic change in IMS-based industries. Components demand and trade in components increased with the emergence of internet and an increase of mobility worldwide. On the supply side, a further deepening of globalisation – trade stimulated by a dramatic decrease in transport costs (container shipping; air transport) but also a deepening of offshored outsourcing - added to this development. Eastern Asia, in particular the Asian Pacific saw a rise in market share in components from 25% in 2001 to nearly 50% in 2009, whereas Europe’s market share declined from 20% to 13%, and market shares of Japan and North America dropping even more drastically (World Semiconductor Trade Statistics).

During the 2000’s fabless companies and foundries strongly gained in importance. Integrated device manufacturers (IDMs) – semiconductor companies designing, manufacturing, and selling integrated circuit (IC) products in-house – became less prominent. Instead, a rise was observed in fabless semiconductor companies and a further outsourcing production to third parties. Over the last decade, numerous European producers either transferred manufacturing operations to Asia or moved toward an asset-lite or
Another parallel but related development was the spinning out of the semiconductor operations of large European OEMs in the early 2000’s. Both Infineon (spin-out of Siemens, 1999) and NXP (spin-out of Philips, 2006) are successful examples of this strategy.

Intel, the number one semiconductor company is – despite the rise of fabless and foundries – still an IDM. According to Intel, it cannot only market chips faster, but do so with fewer faults than foundries (The Economist, 2012). Yet there appears to be also room for different business models, such as the model of ARM, a UK-based chip design firm which specialises in chips that economise on energy instead of maximising processing power. The business model of ARM is built on selling licenses for semiconductor designs or its architecture; licencees pay a fee and a royalty of 1-2% per chip. ARM lies as a result at the heart of an eco-system of companies, with 270 licensees and 830 licenses, consisting of chipmakers, device producers, designers of chipmaking tools and software companies (The Economist, 2012).

Table 12 Semiconductor companies (global sales, in mln US$), 2010

<table>
<thead>
<tr>
<th>2010</th>
<th>2009</th>
<th>Company</th>
<th>Sales 2010</th>
<th>Sales 2009</th>
<th>Change %</th>
<th>Business model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Intel</td>
<td>40.154</td>
<td>32.325</td>
<td>24</td>
<td>IDM</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Samsung</td>
<td>32.455</td>
<td>21.273</td>
<td>53</td>
<td>IDM</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>TSMC</td>
<td>13.307</td>
<td>8.989</td>
<td>48</td>
<td>Foundry</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>TI</td>
<td>13.037</td>
<td>9.697</td>
<td>34</td>
<td>Fab-lite</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Toshiba</td>
<td>13.028</td>
<td>9.537</td>
<td>37</td>
<td>Fab-lite</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>Renesas*</td>
<td>11.650</td>
<td>9.649</td>
<td>21</td>
<td>Fab-lite</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>Hynix</td>
<td>10.432</td>
<td>8.420</td>
<td>26</td>
<td>IDM</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>STMicroelectronics</td>
<td>10.212</td>
<td>8.406</td>
<td>21</td>
<td>Fab-lite</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>Micron</td>
<td>9.057</td>
<td>5.450</td>
<td>66</td>
<td>IDM</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>Qualcomm</td>
<td>7.204</td>
<td>6.409</td>
<td>12</td>
<td>Fabless</td>
</tr>
</tbody>
</table>

Source: IC Insights, 2011; company reports; SEMI, 2011. * Merger of Renesas and NEC.

During the 2000’s Europe witnessed a general decrease in its manufacturing capacity in semiconductors. The European semiconductor industry still has market leadership - not anymore in mass market production, but in a number of specialised niche segments, notably:

- Automotive components and telecommunications (Infineon, Germany; NXP, the Netherlands; STMicroelectronics, Switzerland; Bosch, Germany)
- Lithography (ASML, the Netherlands)
- Hyperpure silicon wafers (Siltronic, Germany)
- Silicon-on-Insulator (SOI) for microchips (Soitec, France).
Europe has been able to maintain strengths in a number of key applications, with leadership in radio-frequency (RF), analogue/mixed signal and More than Moore technologies. An important future challenge, however, is to maintain its built-up advanced manufacturing capabilities.

4.2 Dynamics in IMS and IMS-using industries: Europe in a global context

The semiconductor industry is part of the wider micro- and nano-electronics industry, broadly defined as micro- and nano-electronics materials, equipment and semiconductors (see HLeG KETS, 2011: 15). IMS industries and the micro- and nano-electronics industry partly overlap. A significant part of the IMS and IMS-using industries, however, consists of large OEMs mostly outside the semiconductor industry narrowly defined. Examples of European OEMs are Siemens, Philips, Bosch, Mannesmann, Continental/VDO and TomTom, but also car manufacturers such as Daimler, PSA Peugeot Citroen, BMW and others.

There exists a direct relation between future market growth potential for IMS-based applications in Europe and the presence of strong European companies in upstream sectors.

Most manufacturing of mass market electronics products such as PCs and mobile phone and other household consumer products has in recent years moved to Asia. In some cases European companies are still actively involved. Many of the European OEMs that were originally active in mass market electronics consumer products appear to have reformulated their business strategies and have moved on to other higher value added and lower volume specific niche markets. Two prominent examples are Siemens and Philips. Over the last decade Siemens sold its semiconductor, as well as its mobile phone and computer operations and moved, backed by various acquisitions worldwide, into new domains such as wind and solar energy, security systems, and medical solutions/diagnostics. Philips gradually moved out of the electronics consumer mass product market, spun out its semiconductor operations, and made a strategic turn to the medical systems market.

Future market growth potential for IMS-based applications for European industry appears particularly strong in the automotive, industrial machinery and engineering sectors, in healthcare systems and industrial process control equipment.64 It is here that Europe has maintained or expanded its

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64 This is indirectly supported by scoreboards and other accounts of the state of play of industry worldwide. One example is Thomson Reuters’ Top100 Global Innovators (2011) which puts US companies as leading the ranking of semiconductors and electronic component manufacturing with 50% of the top 100 global innovators. Similarly, Asia is leading in computer hardware manufacturing and automotive
importance as a manufacturing base for electronics applications and as a market for electronic components and miniaturised systems. Europe’s leading position in these domains appears primarily to be related to the presence of strong existing ecosystems, in which OEMs, innovative SMEs and public research organisations are still able to develop innovative solutions. Proximity to and interaction with client industries is a crucial factor for success in these eco-systems.

Whether current Europe’s competitive advantage in these areas can be maintained and expanded in the long term depends to an important extent on whether these eco-systems can be maintained and made even stronger. The ability to establish triple helix combinations and thus further strengthen the innovative ability and collaboration between IMS and client industries, research institutions and government is crucial. Co-operation and joining hands at the European level appears key. Otherwise is doubtful that significant volumes of production, apart from design, can be retained in Europe in the longer term. And even design may be at risk in the longer term without such cooperation. For also design knowledge matures, ages, and expires with the process-knowledge from the production and knowledge of the customer. Customers will only provide their know-how in case of sufficient confidence in the abilities of the designer.

One of the key questions for the future is whether these ecosystems can be kept and whether existing manufacturing capacity is still sufficient to face longer term future challenges. This applies longer term both the development and production of advanced semiconductors and applications based on new emergent technologies such as More than Moore and beyond CMOS.

4.3 Changing strategies and business models in IMS industries

4.3.1 Rise of systems integrators and increasing role of supplying SMEs

A review of publicly available information on business models of the nano-electronics industry reveals that nano-electronics companies in general either do not have an explicit strategy or are not willing to share it. The analysis of the business models reported in this section is therefore also based on interviews with representatives of companies and research institutes as well as additional contacts with sector-experts.

An immediate and evident conclusion from the desk research is that the industrial actors in the nano-electronics sector play different roles in the innovation system. As summarized by (Mengematic and Walsh 2012): “[…] large firms play a central role in ‘translating’ new knowledge between public research and industry in technologies […] with SMEs playing the role of manufacturing. Europe is leading the world in machinery manufacturing (Sweden, Germany) and France leads the world in scientific research, and with most companies in the top 100.
specialized providers.” In biotechnology for example, these role are completely reverse.

An important development, as we already observed in section 4.1, was the gradual demise of the Integrated device manufacturers (IDMs) model – semiconductor companies designing, manufacturing, and selling integrated circuit (IC) products in-house – and the rise of fabless and foundries. In the heart of integrated miniaturised systems development and production, another newer but in its consequences rather similar development is taking place. OEMs nowadays rely for their manufacturing production far more than in the past on the independent and innovative role of supplying SMEs within the eco-system. These preferred suppliers are given functional specifications, but not any longer uniform full-fledged product specifications according to which products should be made. An example is that large manufacturers in the nano-electronics sector seem to outsource part of the development of production facilities to equipment manufacturers, such that they are buying production “functionalities” and not purchasing tools / machines based on detailed technical specifications. This model gives more leeway to the SMEs concerned, but also leaves a bigger chunk of the innovation efforts to the wider ecosystem and poses new challenges for the innovation capabilities of SMEs. Overall, the role of system integrators in developing IMS is rising throughout the industry, with integration up front of the innovation process rather than at the end.

Similar to the rise of the fabless and foundries, this recent development adds to the trend of specialisation and increase in flexibility in the industry, allowing companies to benefit from potential economies of scale even more. At the same time, this development puts more emphasis on the importance on the quality and robustness of existing eco-systems and on collaboration generally.

4.3.2 Valley of death important hurdle for SMEs
For SMEs involved in the production of integrated miniaturised systems, it seems almost impossible to complete the innovation process from research results to actual application in the market (“valley of death”, see for instance ENIAC-AWP 2012). In order to address at least part of the “gap”, these firms are looking for possibilities to share for example production facilities for the assembly of products in order to limit costs (Jurvetson 2004).

The sharing of production facilities offers one solution. Another could be increased funding opportunities to bridge the valley of death. Both private and public funding in Europe appear to act as a barrier to the evolution not only of

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65 As an example, see [www.apcenter.nl](http://www.apcenter.nl). Advanced Packaging Center (APC) provides support “[...] to get from proto-typing to mass production for MEMS, Sensors and advanced IC packaging [...] by offering research, development, qualification, prototyping and small to medium volume manufacturing services.
start-ups but especially for young companies that want to scale up manufacturing capabilities and explore markets. The lack of private funding appears, since the economic crisis of 2007, is a more general phenomenon throughout the EU and not restricted to IMS. The crisis has led to existing sources of private equity and venture capital drying up and to a more risk-averse stance by many private investors. Despite attempts by member state governments to complement private venture capital with public risk capital, so far results are limited.

4.3.3 Context of uncertainty...
The field of micro- and nano-electronics is still in the early stages of its lifecycle. This relative immaturity poses difficulties for companies in identifying R&D needs that are of strategic relevance for their core activities, and those that concern pre-competitive stages of the development of new products. The first type of needs should be addressed preferably by companies’ own R&D capacity, the second could be shared in collaboration with competitors to limit the cost. This relative immaturity and corresponding uncertainties in how the micro- and nano-electronics sector will evolve also results in strongly diverging business forecasts and expectations (see also Westkämper 2007). The interview reports provide a mixed view on the future technological scope of the sector. It is hinted that certain actors in Europe lost the battle concerning More than Moore, and it is suggested even to focus all efforts on beyond CMOS. A univocal strategic approach, however, cannot be formulated.

Because of these uncertainties, firms in practice opt for the spreading of risks in future business portfolios by selecting a wide range in focus. In terms of applications a good example is found in the automotive supplying industry. On the one hand the industry is working on smart devices to enable the market roll-out of full hybrid and electric cars in Europe, but on the other hand the same industry – and sometimes even same company appears to be working on making the conventional combustion engine even more efficient. Efficiency claims in the coming 20 years lie here in the order of magnitude of 30%, with the EU industry leading worldwide.

Companies in Europe tend to be conservative and risk-aversive in their approach towards the adoption of knowledge and concepts resulting from new research.

4.3.4 ... And lack of product and production standards
Because of the fact that nano-electronics but also new application domains are in the early stages of their lifecycles, universal product and production standards are often lacking. This hinders development into further maturation of the market, and limits the time horizon in forecasts and strategies. Lack of industry standards in production but also in the use of new technologies and/or products, for example resulting in a lack of adequate public infrastructure (such as in uploading batteries in EV) may act as a barrier in
further development. Also, business forecasts and expectations and the spreading of risk in the choice of future business portfolios often prevent companies from “betting on one horse” only and may have a slowing down effect (see – again - the former example of the automotive supplying industry). Company strategies in IMS are often still dominated by the use and deployment of proven technologies.

4.3.5 Market fragmentation and lack of economies of scale...

Lack of harmonised policies at the EU level and a lack of standardisation may lead to market fragmentation and problems in benefitting from potential economies of scale. A prime example here is the market for healthcare /medicare/ medical systems. National legislation and national specificities, such as prevailing health insurance systems and approval procedures, make that the healthcare market in Europe, also for IMS-based applications, are very much national markets. Fragmentation prevents companies from benefitting the advantages of a large home market. European companies indicate that alternative markets where such market size does exist, such as the US or China, are more interesting in terms of investment, market roll-out as well as profit.

Production numbers of (products based on) integrated miniaturised systems also appear limited because of their relatively short lifecycle. In certain markets, especially in end-consumer applications, a wide offer of different and new products is essential to satisfy almost constantly changing consumer preferences. Being able to satisfy these demands requires to avail of flexible production facilities, are able to address constantly changing technological possibilities and product functionalities. System integration seems the answer for small actors in the sector to address market needs. System integration requires, however, for advances planning of production and more collaboration, in manufacturing as well as in innovation.

4.3.6 Cost competition in non-premium markets...but labour costs differentials decreasing

Especially for non-premium market products where patenting is less frequent and copying and imitating is more prevalent, especially in mass consumption markets, European industry is facing strong cost competition from Asia and in particular China. With time, this pressure is likely to rise further. Only leading edge and innovative products with a high degree of complexity might be able to withhold the impact of fierce international competition. Companies producing for high-end high value niche markets rather than global mass markets are more likely to survive in the future.

Labour costs differentials between Europe and, for example, Asia are still not unimportant, but are becoming less. Increasing labour market flexibility in developed economies and wage inflation and a decrease in labour surplus make that labour costs worldwide tend to converge more rather than diverge.
The one-sided outsourcing of production capacity trend by the European nano-electronics and other IMS using industries to Asia and other low-cost regions is coming to an end. Lately, an - although still hesitant - return of manufacturing capacity back to Europe can be observed. Whether this recent trend will also apply to the nano-electronics and IMS-using industries is dependent on more than labour costs or total production cost alone. The presence and especially the growth potential of markets in the emerging economies is another important factor. A different but related trend is the emergence of Asian, in casu Chinese-owned production infrastructure in Europe.

### 4.4 RTDI funding and public support in Europe

Strategies and business models are primarily defined by market dynamics. R&D and innovation programmes by national and supra-national governments, can stimulate and direct innovation efforts, and through that, can (co-)determine and direct developments in favourable directions for the economy at large.

Especially the Nordic countries in Europe have implemented explicit R&D and innovation policies addressing ICT-related sectors, with a strong focus on increasing BERD (JRC 2011). There is no insight yet in the impact of this targeted government intervention on the nano-electronics sector. Also various EU initiatives have been implemented to prepare for the future. One example – by far the largest microelectronics industry project initiative in Europe - is the Nano2012 project launched in 2007 by STMicroelectronics, CEA-Leti and IBM with the goal of developing breakthrough 32 nm and 22 nm etching technologies, with US$ 1.25 bn in capital expenditure and €2.3 bn 12 R&D spending.

Important R&D funding for European industry comes from both the Member States and Europe’s current R&D Framework Programme FP7. In preparing for the future , a vital role is played by the European Technology Platforms, in particular ENIAC (nano-electronics), Artemis (Advanced Research & Technology for EMbedded Intelligence and Systems), EPoSS (European Technology Platform on Smart Systems Integration) and Photonics21 (European Technology Platform Photonics).

To further strengthen the innovation system, the next EU R&D Framework Programme will establish links with the dedicated EUREKA programme on nano-electronics called CATRENA.

#### 4.4.1 Importance of pilots and economic value

Survey results suggest that main challenges for the introduction of IMS applications are related to applied research and pilots. In the interviews, several respondents expressed concerns about the need for proof about the value of innovations, or new applications, in order to stimulate innovation. In case the value of new applications is not known or proven, new applications
might not become available on the market. This is especially the case in markets where safety and reliability issues are important, such as in the mobility and health and ageing domain. In several interviews, conservative attitudes were mentioned as barriers for adoption of IMS technologies.

More research is needed on the cost-effectiveness of new applications. Especially in the medical devices domain, the added value of new applications often is not clearly known (see e.g. WHO, 2010). There is a need for applied economic research in order to *a priori* assess added value. Also for sustainable mobility and energy applications a need for pilot projects to prove the added value of devices was voiced, in order to speed up innovation and adoption of technologies.

**4.4.2 Room for improvement of EU public RDTI support**

No results of formal evaluation of the impact of public RTDI initiatives are known, although these programmes do seem to have an important role in shaping research demand and in clustering R&D capacity and efforts. Remarkably, however, survey findings of this project unanimously point at the lack of public research funding as one of the most important barriers for future IMS-based applications.

In-depth interviews offer a further explanation for this lack of public funding argument. Interviews point at the perceived difficulties in acquiring EU public funding but also high administrative burden and the lack of effectiveness of collaboration in EU projects. Competition for EU R&D funds – both in FP7 and in EU regional funds for innovation – is strong, with many applicants applying and a relatively small success rate in terms of getting a proposal granted.

Administrative requirements needed to apply for European R&D and innovation support are also considered as high, by some companies even prohibitively high, and higher compared to most national support programmes. Moreover, lead times in terms of the waiting time between the submission of proposals and the final decision for granting are seen as very long compared to national public funding. The administrative burden does, moreover, not disappear once support has been granted; checks and controls during and ex post ask considerable attention.

The interviews showed mixed results as the size of project in terms of number of partners. Some interviewees argued that multiple partner projects are beneficial for the integration of systems. In developing systems, integration often takes place at the end of the development process. For sustainable mobility this relates, amongst others, to safety. Especially for automated driver solutions the reaction of the user to the applications needs to be assessed before it can be integrated into the vehicle (first attempts are usually not successful). For this reason, companies start with a minimum number of solutions and then start to integrate the solutions. In large multiple partner
projects, more applications can be incorporated and tested so integration becomes necessary at the beginning of the project.

Other interviewees advanced that the size of project consortia in terms of number of participating organisations, and the often experienced large differences in experience, knowledge and expertise between project partners, the overall effectiveness of collaboration and R&D efforts at large is rated as low / poor. This sincere and honest warning was especially heard from large leading OEMs. Political criteria in granting project proposals rather than scientific excellence seem to prevail. Smaller, more targeted consortia of 3-4 project members are preferred by industry, but are currently not the rule but rather the exception.

Lack of public funding also has a straight financial reason. According to company interviews public support rates altogether often come close to only a 1 to 2% share in total company R&D and innovation investment. Together with the strong competition for EU projects, the relatively high administrative burden in the application as well as the implementation phase of project, the size and ineffectiveness of project consortia and, on top of this, the minor contribution of public support in company R&D budgets – make that the drive and urgency to make an effort to attract EU public funding seems to be decreasing instead of increasing.

As a positive example and possible benchmark for Europe the German model of public R&D and innovation support was more than once mentioned in the interviews. Smoother, less administratively burdensome and shorter procedures in getting funding combined with a smaller and therefore better workable partnerships in R&D collaboration make the German model according to companies a preferable model compared to current and future (Horizon 2020) EU model of public funding.

Last but not least should be mentioned the importance of providing more emphasis and support to the last stage of the innovation cycle. In various application domains the need for active support in demonstration and piloting – “prototypes at work” were voiced. Currently in the RTDI chain, the innovation part with pilots and demonstration gets the lowest level of public support. If Europe is to compete with Asia and North America on a more levelled playing field, this aspect should be given more explicit attention than it nowadays gets, both in national and EU funding programmes.

4.5 Conclusions
The importance of the micro- and nano-electronics industry for Europe is undisputed and the market potential high. Europe has been able to maintain strengths in a number of key applications, with leadership in radio-frequency (RF), analogue/mixed signal and More than Moore technologies. An important future challenge, however, is to maintain its built-up advanced manufacturing capabilities. Europe’s leading position in these domains
appears primarily to be related to the presence of strong existing ecosystems, in which OEMs, innovative SMEs and public research organisations are still able to develop innovative solutions. Whether current Europe’s competitive advantage in these areas can be maintained and expanded in the long term depends to an important extent on whether these eco-systems can be maintained and made even stronger.

The context of uncertainty and the lack of product and production standards in nano-electronics, but also market fragmentation and lack of economies of scale and limited production numbers, act as barriers. System integration seems the answer for small actors in the sector to address market needs. This asks for extensive planning of production, and collaboration in innovation. Another important factor is increased funding opportunities to bridge the valley of death in order to get applications on the market.

The main challenges for the introduction of IMS applications are related to applied research and pilots. Moreover, more research is needed on the cost-effectiveness of new applications, especially for medical devices the added value of new devices is not clearly known.

Finally, the drive and urgency to make an effort to attract EU public funding for industry seems to be decreasing instead of increasing because of the strong competition for EU projects, the relatively high administrative burden in the application as well as the implementation phase of project, the size and ineffectiveness of project consortia and, on top of this, the minor contribution of public support in company R&D budgets. This is perceived as one of the most important barriers for future IMS-based applications.
5. Competencies and technologies needed to realise the future miniaturised systems

5.1 Today's status of research efforts

To identify competencies and technologies needed for integrated miniaturised systems today and in the future both technological opportunities and demands must be analysed. Furthermore it is to determine whether identified technologies in the period under examination conditions for a fundamental change in the technological paradigm. That is also investigating whether there are technological options that can form the basis of a change of technological paradigm.

The following gives an overview on the state of the art in integrated miniaturised system technologies. Based on that analysis, the barriers and drivers for the considered technologies as well as the position of European actors in those technologies can be analysed.

The secondary data analysis as well as the patent analysis shows that without any doubts miniaturisation makes economic sense and has become an important driver of R&D and manufacturing. Consumers for intelligent and multi-functional products generated an increasing demand. Few other products can better demonstrate impact and benefit of the miniaturisation of systems than the mobile phone. Not only systems have been changed, due to the impact of these miniaturised telecommunication system the completely environment changed, including markets, services, players, customer behaviour, business models, regulations, and so on. The same sets are currently not only used to transmit voice messages but they can also transmit colour pictures and video images, e-mails, as well as access to the World Wide Web. These smart miniaturised intelligent and multifunctional devices have become a fact of day life for billions people around the world.

This quite evident persistent trend in market demand for intelligent, multifunctional products seems to be only met by including more and more "performance and functionalities" into more handy finished products.

The advantages for providers are undisputed and offer wide space to stay clearly apart from competitors. Small systems are mobile per se. They can move or stop more quickly than larger systems due to low mechanical inertia. They are thus ideal for precision movements and for rapid actuation. Miniaturized systems encounter less thermal distortion and mechanical vibration due to low mass. Miniaturized devices are particularly suited for biomedical applications or applications into harsh environments due to their minute sizes. They have also a higher dimensional stability at high temperature because of low thermal expansion. Miniaturisation means less space requirements. This feature allows the packaging of more functional components in a single device. Less material requirements in smaller systems
mean low cost of production and transportation. And at least, being small, they can be better mass-produced in batches.

For usage of these benefits for advantages in competition, the question for the future is, which competencies and technologies are necessary, which paces of development have to be used and which barriers will be expected.

The miniaturised systems cover a broad field that comprises nano-electronics and other technologies. As said before, because the study is not limited to nano-electronics, the focus will be on miniaturised systems. However, nano-electronics will play an enabling role for numerous miniaturised systems.

Production of miniaturised device components and engineering systems of micro- and nano-scale is clearly a challenge and will stress the capability of current machine tools. Shaping devices and components of complex geometry in micrometer scale with high dimensional accuracy requires the use of specific and carefully controlled physical as well as chemical processes. Many of these processes result in adverse or intrinsic effects that need to be accounted for in early stage of design considerations. The nature of the minute sizes of these future products creates also many problems in the whole supply chain. These kinds of challenges are illustrated in Figure 13. The figure shows very impressively the coherence between the magnitude of aspired element size and the required accuracy of manufacturing tools.

Figure 13 Norio Taniguchi’s Precision Chart
So, the identification of major technical and scientific competencies, challenges and drivers, will be tackled from within the nano-electronics domain (e.g. challenges related to miniaturisation, IC-design, energy resourcing) as well as from external drivers (a demand for smaller and smarter systems from various application domains). Some of these challenges and drivers will be generic, while others will be domain specific (e.g. ICT-neurons interactions in health domains).

Such a view makes first of all sense if the state of the art in research in the investigated area will be defined as a starting point. As this status, this includes the portfolio of all technological alternatives, which are available for all further product developments.

Of further interest for the future of integrated miniaturized systems is particularly how the penetration of miniaturisation technologies in Europe will be, how they will influence both industry and research.

How deep is the "penetration depth", what is status of knowledge on technologies in the "innovation pipeline" and what is the degree of mastery of this portfolio of technological alternatives?

Consensus among experts was reached that currently the applications covered by advanced silicon CMOS technology are enabled by the permanent scaling of the MOS transistor (MOSFET) and the reduction of the cost per transistor by a factor of greater 100 in more than 40 years.

Figure 14 Scaling path

Source: S.Deleonibus
The further development seems to be clearly defined by ITRS, playing a major role in defining the specifications to be reached by silicon-based CMOS-technology in order to fulfil criteria for further application requirements.

Figure 15 Potential Disruptions in ITRS Roadmap

But this apparently clear defined path evolution contains simultaneous barriers and effects, which are able significantly to slow-down the evolution of CMOS by 2020, e.g. in case of lithography, materials and others.

Increasing long mask-write and cycle-time or fabrication of optics or the mastery of (layer) interconnects because of mitigate impact of size effects in interconnected structures. Likewise problems of patterning, cleaning, and deposition at nano-dimensions, in case of packaging, e.g. 3D-packaging, in cases of layer deposition on atomic level as well as in case of design of transistor as the key element of the circuits in the future. Last but not least the challenges in case of materials to achieve advanced properties and performance - e.g. carrier mobility, sufficient low contact-resistivities or defect minimisation. As a result fundamental limits of devices and materials, system level limits, power density issues and cost have to be stated.

Nevertheless the development of CMOS technology is expected to continue the following years; however, already today a stage is reached where state-of-the-art semiconductor circuits meet more and more physical limits. Limits concerning the economy of manufacturing, caused by effects of device scaling could be reached even before that.
Figure 16 The "downscaling path"

Source: The Economist

Beside this “down-scaling” path to new devices for signal processing, new approaches, dealing with new ideas and alternative technologies in order to create alternative devices able to replace CMOS technology in the 2020 or beyond timeframe; seems to be necessary – and are under investigation. These approaches aim at technologies that would extend the functional scaling of signal processing substantially beyond the down-scaled CMOS. They are represented by the usage of functional diversification – the More-than-Moore approach. The second is to develop fundamentally new approaches to meet the requirements of data processing – the beyond CMOS-approach.

Figure 17 The vision of CMOS

Source: ITRS
5.1.1 The “trinity” of development

Using this model for the further investigation, one can try to analyze and assess several trends and drivers in nano-electronics’ development. Using the direction of development (scaling, diversification, substitution) as a reference, a kind of comparability will be induced. The pushing for continuous scaling (More Moore) is today accompanied by the simultaneous introduction of additional functionalities such as micro/nano-system, RF, analogue, biochips on a conventional logic or memory circuits (More than Moore).

In addition to this, new technologies such as graphene and nanowires (beyond CMOS) are also expected to emerge from the area of Nanosciences and Nanotechnologies, possibly leading to breakthroughs for new, unexpected applications.

With the respective status of challenges as the starting point the main directions and challenges of the nano-electronic technology development will be investigated.

5.1.2 More Moore – Straight forward

The 'More Moore' domain is commonly defined as an attempt to further develop advanced CMOS technologies and reduce the associated cost per function.

Figure 18 Extended CMOS- the 22nm-3D Tri-Gate-Device

Source: Intel

This trend for increased performances will continue, while performance can always be counterbalanced against power depending on the individual application, sustained by the incorporation into devices of new materials, and the application of new transistor concepts.

Currently 70% of the total semiconductor components market is just directly impacted by advanced CMOS miniaturization achieved in the More Moore domain. This share comprises three component groups of similar size, including microprocessors, memories, and various digital logic. Figure 19 shows the revenues of European companies generated by device type in 2008. Now, with the market exit of Qimonda and the acquisition of Numonyx
by Micron, the market for memories is not at all of any significance for European semiconductor revenues.

Figure 19 EMEA semiconductors companies’ revenue (€b) by devices type

![Pie Chart showing EMEA semiconductors companies’ revenue by devices type](image)

Quelle: Gardener Dataset 03-2009

Highest revenues in Europe are generated by application specific devices (ASIC and ASSP) that represent about 50% of the total European revenues.

For these categories, there are in the midterm (that means during the next decade) a number of general as well as specific technological challenges to be solved to ensure the continued application of these key elements in miniaturized systems. These structures, technologies and materials are already the object of investigation of R & D teams and are matured so that they could be implemented in mid-term in industrial processes.

A major part of semiconductor device production is devoted to digital logic. In this category key considerations are speed, power, and density requirements and goals and the key theme is continued scaling of the transistors in order to improve device performance.

This scaling is defining the main direction of further R&D efforts, including material and process changes such as high-κ gate dielectric, metal gate electrodes, strain enhancement and as new challenges, new structures such as ultra-thin body fully depleted SOI and multi-gate (MG) MOSFETs (such as FinFETs). Ultra-thin body fully depleted SOI are an extremely attractive solution. These devices are built on an ultra-thin SOI substrate, enabling an undoped channel, drastically cutting short channel effects, eliminating Random Doping Fluctuations (RDF) issues and exhibiting excellent threshold voltage control.
With CMOS logic memories, mainly DRAM and non-volatile memory (NVM), form together the predominant majority of semiconductor device portfolio. For both DRAM and NVM, detailed technology requirements are considered.

For DRAM, the main goal is to continue to scale the footprint of the 1T-1C cell. The issues are vertical transistor structures, high-k dielectrics to improve the capacitance density, and meanwhile keeping the leakage low.

The majority of NVM are Flashs, with a fundamental issue of non-scalability of tunnel oxide and interpoly dielectric. Other non-charge-storage types of NVM are also in discussion, including ferroelectric RAM (FeRAM), magnetic RAM (MRAM), and phase-change RAM.

Emerging technology generations require the implementation of new materials and new processes at a rate that exceeds current capabilities for gathering sufficient knowledge and data to ensure product reliability. But uncertainties in reliability can lead to performance, cost, and time-to-market penalties. These issues generate a broad bandwidth of challenges on testing and reliability modelling with a need of significant research and development.\(^{66}\)

5.1.3 More than Moore – An indication of a new paradigm?

The further scaling process in the semiconductor industry is demanding undoubtedly an exponential rise in the cost of process development as well as

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\(^{66}\) As the major R&D challenges and issues observed in this area of nano-electronics, also reflected in existing technical literature, international scientific reports and industry roadmaps (see bibliography), one can find the following (as examples):

- Fully depleted SOI and multi-gate (MG) structures
- Source/drain series resistance within tolerable limits
- Scaling of EOT (higher \(\kappa\) materials (\(\kappa > 30\)))
- Threshold voltage tuning and control with metal gate and high-\(\kappa\) stack
- Inducing adequate strain
- Adequate storage capacitance with reduced feature size (implementing high-\(\kappa\) dielectric)
- Low leakage (transistor and storage capacitor)
- Low resistance for bit and word lines
- Higher bit density and to lower production cost in driving toward 4F2 cell size
- Adequate noise margin and control key instabilities and soft-error rate
- Non-scalability of tunnel dielectric and interpoly dielectric in flash
- Lithography and etch issues with pitch scaling
- High gate coupling ratio in floating-gate flash
- Threshold voltage shifts due to traps, carrier injection, etc.
- Mobility degradation
- Failure mechanisms resulting from high-\(\kappa\)/metal gate and new doping/activation processes
- Failure mechanism resulting from length scales or new device structures
- Process variability
- Control of short-channel effects
- Vdd scaling
- Controlling sub-threshold current
setting up of wafer-fabs. This initiated a rethinking in the industry on business models and its dedication to Moore’s Law.

The change in thinking aimed at conquering markets, which focus on system integration rather than transistor density. Since most new markets do not need large volumes of transistors, the industry can exploit its current base of wafer manufacturing plants, which makes these new markets very attractive.

Figure 20 Examples of MM&MtM - Applications vs. Technologies

With this rethinking a major paradigm shift is taking place now, however, both in the technology push and in the application pull. The result of this paradigm shift is an increasing incorporation of functionalities into devices that do not necessarily scale according to ”Moore’s Law“, but provide additional value in different ways.

Figure 21 The More than Moore Principle - Added Functionality
The "More-than-Moore" approach is about functional diversification and allows for the non-digital functionalities to migrate from the system board-level into the package (SiP) or onto the chip (SoC).

From the application pull perspective, it has become clear that customers and societies have lost interest in new generations of applications and devices that only feature more computational power than their previous generation. For improving the customer experience, and for solving the societal challenges, radically new devices are needed that are more closely and more invisible, more ubiquitous integrated in every-day life, and these require sensors, mechatronics, analog- and mixed-signal electronics, ultralow- power or high-voltage technologies to be integrated with CMOS technology. Devices that embed this mix of technologies represent the "More than Moore" approach: e.g. combining generic CMOS-technology with new technologies for building more innovative, dedicated, smarter and customer-tailored solutions.

This new era of added-value systems will certainly trigger innovation, including new methodologies for architecting, modelling, designing, characterising, and interdisciplinary collaborating between the domains required for the various technologies combined in a “More than Moore” system.

The “More than Moore” trend is to integrate multiple technologies into miniaturised systems. This is the path to achieve common goals such as application-driven solutions, better system integration, cost optimisation, and time to market. Solutions meeting that changes will drive industry into a direction of more diversity and wider ecosystems.

Characterisation of this development can be done by the usage of System-in-Package approach with integration of digital and non-digital functions in one module and a high diversity of technologies, causing heterogeneity of materials and designs.

Moore’s Law, which dominated process technology in semiconductors for decades, will remain in a limited number of high volume areas. But it might be terminated when the boundaries of physical ability or economic feasibility are reached.

Today’s increasingly sophisticated markets demand solutions that optimise specific applications. In turn this promotes the pace of innovation, providing OEMs with more opportunity for differentiation. Early collaboration also ensures flawless integration of the integrated miniaturised systems in OEM products, shortening development time and costs, and enabling early market access. Here are some more examples of how a More-than-Moore approach is already delivering technology developments that offer interesting business opportunities and adding value to people’s daily life.
Examples of these new markets are medical, solar and industrial- they will be objects of further investigation. In the last few years these verticals have opened up in terms of market opportunity and technological advances in analogue and sensor integration. The More than Moore approach refers to a set of technologies that enable non-digital micro/nano-electronic functions, and non-electrical effects for system integration.

Figure 22 Cell Interaction with Carbon Nanotubes

They are stemming from silicon technology but do not necessarily scale with Moore's Law. The More than Moore devices typically provide conversion of several physical inputs, such as mechanical, thermal, acoustic, chemical, optical and biomedical, to digital data.

Because of this different technological base the technology drivers and R&D challenges are possibly different from the More Moore approach, e.g. with new, functional and compatible materials or the integration of smart, miniature, integrated sensor systems, including advanced signal conditioning and processing circuitry.

Figure 23 "Megafunction" Electronic a 2006 Vision
5.1.4 Beyond CMOS – An Alternative path to a new paradigm?

Whereas the outstanding progress in microelectronics has resulted mainly from the scaling down of CMOS technology (as mentioned above), detrimental effects are playing an increasing role, leading to a difficult and costly miniaturization of MOSFETs and even more to a future end of the classic scaling. This is why many different approaches have been conceived, either to avoid the problems, making possible an extension of the conventional top-down route, or to provide solutions for the era beyond CMOS. They are known as evolutionary or disruptive solutions, based on introducing new devices, systems architectures or paradigms. The "More of Moore" is about equivalent scaling, which occurs in conjunction with, and also enables, continued Geometrical Scaling plus non-geometrical process techniques that affect the electrical performance of the chip.

Figure 24 Beyond CMOS - Technologies converge for higher value solutions

Beyond the CMOS probably also bets on non-charge based devices. Molecular devices using other state variables (e.g. spin, molecule conformation) to code a logic state are still challenging and exciting objectives. In addition, new technologies such as graphene and nanowires are also expected to emerge from the area of nano-sciences and Nanotechnologies, possibly leading to major breakthroughs for many applications.
To reach the requirements alternative paths beyond current state a selection of emerging devices being considered to go beyond CMOS has been found.

Technological challenges of the Beyond CMOS approach and object for technological R&D efforts will be:

- Atom scale technologies,
- Spin electronics,
- Molecular electronics,
- Ferromagnetic devices,
- Nanoelectromechanical systems,
- Organic/plastic electronics,
- Bio-sensors,
- Nanophotonics,
- Phononics,
- Plasmonics,
- Bio-inspired electronics,
- Nanomechanical computing devices,
- Quantum computing devices,
- Ultimate e-beam and photon lithography,
- Emerging nano-patterning methods,
- Hybridisation to different platforms,
- New Materials:
  - 1D charge state materials,
  - Molecular state materials,
  - Spin state materials,
  - Strongly correlated materials,
  - Nanometer scale contacts/ interfaces,
  - Nanostructured materials assemblies,
- Reliability issues.

5.2 Functionalities, Applications and Technological Options

With the increase in complexity in the electronic systems, there is a growing need for more and more on-chip functionality with simultaneous increasing requirements concerning smaller size, lower weight, and less power consumption. The level of device integration seems to have reached its near-saturation in the two dimensional geometry unless the technology scaling is further done in the monolithic silicon technology. Technological alternatives emerge, e.g. 3d-packaging, and offer new solution options to achieve lower area, smaller size, lighter weight, timing delay, etc. and first of all quick time to market.
The demands for a much larger system complexity under a simultaneously pressure of miniaturisation also opens possibilities of using new technological options for system solutions. Smart Systems refers to a broad class of micron to millimetre scale devices. These systems differ from most other semiconductor components in several key respects, including the fact that they are true 3-dimensional structures, they typically have one or more different physical effects on board. They are able to provide some form of physical interface to the outside world. Most current smart systems are not typically fabricated on a standard (e.g. CMOS) or open source process flow.

How depend requirements on the functionality, the implementation of the required functionality into marketable products and the selected technology options each other, what is the mutual influence and how they are implemented by the industry?

Companies will constantly search for new business opportunities, and doing this, they will realize that global challenges such as climate change, sustainable mobility, health and wellbeing or the need of sustainable power supply constitute a huge new market. By creating new and more responsible and sustainable solutions, companies can generate new business opportunities.

The following figure shows an example, how markets / applications are built, influenced or driven by societal requirements. The image shows for example, how markets / applications arise, be influenced or driven by societal requirements. Thus, the increasing environmental consciousness and the conscious use of energy will lead to more energy-efficient products. The effort to realize sustainable mobility will bring an increasing share of alternative drive types on the market. The demands of a changing health-consciousness, accompanied by socially necessary changes in social systems, generate an increased demand for networked point-of-care applications, but also the need to ensure the protection of personal integrity.

This towards portability and delivery of care at the bedside or in the home is accelerating the development of a range of new generation monitoring, display, diagnostic and therapeutic equipment designed to be more compact, accurate and versatile. These systems are geared toward a prevention-oriented, user-driven model for health care that includes innovations such as smart devices that can predict and evaluate situations and circumstances, customized wearable devices, and wireless, secure networked systems – all expected to deliver convenient, user-friendly, intelligent PoC-applications.

Thus, societal needs can become via applications drivers (or barriers) of technological development.
These requirements can be very decidedly and one can therefore find requirement profiles of the required (and usable) technologies. Likewise, general characteristics can be filtered out, which can result in a profile, the underlying framework for technology. Examples include miniaturization, for minimizing the size and weight, the mobility, the independence from the power grid, the ability for networking, the usability, reliability and fault tolerance. Examples are:

For portable consumer goods cost is the primary driver, including hand-held, battery-powered, these products are driven by size and weight reduction. Automotive products using alternative drives, for sustainable mobility, that must operate in harsh environments. Medical products must operate in highly reliable environments, have to be bio-compatible and in extreme cases have to be implantable. Products for energy applications have also to operate in harsh environments have to be very reliable and must be able to take extreme thermal stress because of high current density.

The literature review shows a number of promising new technological approaches for the development of integrated miniaturised systems, but the primacy of the existing CMOS-based approach seems at least in the medium-term perspective to continue.

5.3 Patent Analysis for Nanoelectronic Components

5.3.1 The structure of the patent analysis
Patents are an indicator for the direction of technological developments. Accordingly for answering the question of technological trends in integrated
miniaturised systems a patent analysis was conducted to gain information on trend developments.

The patent analysis was based on the data extraction of the WIPO (World Intellectual Property Organization) data bank. The focus on the analysis was on nano-electronic components. A more general analysis on search terms like smart systems, miniaturized systems, Mems or integrated microsystems did not lead to any significant results. The focus on nano-electronic components allows to identify the applied research intensity in more specific fields rather than in more general fields.

Even when various patent data banks exist (e.g. from the European Patent Office) WIPO provides a reliable source to monitor international technology activities in various countries. This can be seen as a useful trend or technology indicator for various technology areas. The following search terms were used for a more detailed analysis:

- nanoelectronic
- single electron transistor
- tunnel diode
- spin valve
- molecular device
- thin film transistor
- CMOS

It should be noticed that the keyword search can only reflect a trend. The analysis covers the application of nano-electronics as well as the device architectures and fabrication.

5.3.2 Results of the Patent Analysis

The results are quite striking. The most important result of the analysis is that the absolute number of patents is strongly varying from search term to search term. From the analysis it is obvious that more traditional technologies e.g. CMOS or thin film transistors gave the highest hit rate when compared with relatively new nano-electronic devices, materials and technologies. The highest hit rate was obtained for the search term “CMOS” (cf. the following figure). Possible examples for nano-electronics in CMOS-technology are related to the gate oxide thickness or the gate oxide silicon interface. The production processes involved are also in the nano-metre range. The absolute number of patents is rising in the considered time frame, which illustrates the importance of CMOS-technologies in comparison with other nano-electronic
components (e.g. single electron transistors) today and in the near future. Europe in total has in terms of patent applications a good share of about 27% when compared with the rest of the world.

The distribution of cumulated patents between 2003 and 2011 (the years 2010 and 2011 are currently not completely covered) in European countries is shown in the following figure. Germany, the Netherlands, France and Great Britain – in this order – are leading in terms of patents in the area of CMOS patent applications in Europe.

Figure 28 Patent applications for the search term “CMOS” worldwide between 2003 and 2011 (data for 1. Quarter 2011)

Internationally, China is ranked in terms of patent applications on position 13 well after several European countries. This is somewhat astonishing considering that many production activities of integrated circuits are currently taking place in Asia. Also China’s integrated circuit industry on CMOS is expanding rapidly. However, the absolute number of patents is with roughly 20,000 patents – according to WIPO – very high when compared with other search terms. This could underline a strong position of Europe either in the use of CMOS-devices or in terms of production technology.

This is somewhat astonishing considering that many production activities of integrated circuits are currently taking place in Asia. Also China’s integrated circuit industry on CMOS is expanding rapidly. However, the absolute number of patents is with roughly 20,000 patents very high. This could underline a strong position of Europe either in the use of CMOS-devices or in terms of production technology.
More advanced or possible future technologies like molecular devices currently do have from an international point of view a relatively high importance when compared with other relevant search terms. According to the patent analysis the European member states have a patent share of about 12% when compared with the rest of the world. This illustrates a limited number of patented research activities in the European member states. However, the search term “molecular device” is broadly defined and leaves some room for interpretations.

The broader search term “nano-electronic” gave a relatively low hit rate of about 290 patents. This could be interpreted in two ways. The first option is that the term “nano-electronic” is badly defined and there is no internationally accepted borderline between nano- and micro-electronics. The other option is that the patent applicants concentrate more on conventional approaches like CMOS technology which is presumable more relevant for applications and business within the next time.

According to the results of the patent analysis several nano-electronic components are currently under more scientific investigation rather than on the business side like CMOS technologies. The patent analysis makes quite clear that the largest number of patents remains in the current technological paradigm. Changes indicating a paradigm change are not visible from the patent analysis yet. The largest number of patents for the search term “CMOS” clearly underlines that currently no paradigm shift can be observed. It seems...
to be that the patent applicants are following mostly the traditional routes rather than concentrating on new devices. This looks very consistent with the questionnaire results and the majority of the interview results. Beside the importance of “CMOS” and “thin film transistors” — according the number of patents — molecular devices might get an important role in the future. In this area European member states have some weaknesses at least in terms of patents.

5.4 Technological drivers and barriers identified by the survey and interviews

Based on the secondary analysis a survey and interviews have been conducted to identify the major drivers and barriers in integrated miniaturised system technologies. Furthermore the competitive position of European actors in the technologies was subject to the empirical study. The focus of both survey and interviews was on the state of the art in technologies for integrated miniaturised systems today as well as on the expected importance and developments of technologies for integrated miniaturised systems in 10+ years.

The survey and the interviews covered a large variety of actors from sciences, industry and intermediaries. In total 432 persons responded the survey. Interviews have been conducted with actors from industry and sciences. The following figure shows the composition of the survey sample. Furthermore the figure shows the number of respondents that are today already acting in the field of integrated miniaturised systems and those that plan to do so in the future.
The survey validated by the interviews has asked respondents on their view on the importance of selected technological variables on various application domains. Based on that particular information the relevance of current and future developments of technological variables in the application domains have been identified.

The following Figure 31 clearly identifies for technological variables and their attributes the highest priorities by the respondents for today as well as for the future.

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In all following charts the numbers represent the absolute number of respondents that have agreed with the criterion.
The respondents indicate for today a strong priority in Design / Devices and Process Technologies. That is valid for all application domains including those the respondents represent in addition to the three application domain options. Materials and Software / Architecture follow in the three application domains today.

For future priorities the results are changing slightly. Even so Design / Devices and Process Technologies still gain high priority Software /Architecture has gained highest numbers.

The results will be analysed in-depth in the following sections for the various technological variables and their attributes. Since the number of responses had not been sufficient to test the technological variables and their attributes per application domain across application domain view has been chosen.

5.4.1 Drivers and challenges in Technological Variables and their Attributes for IMS / Nano-electronics

Respondents had been asked to indicate the technological variables of highest importance for the development of integrated miniaturised systems /nano-electronics. The respondents could choose among a selection of technologies and their attributes (see Appendix A). In the following main results from the survey will be presented.

Materials

In the survey the respondents had been asked to indicate those materials of highest importance for IMS /nano-electronics and to give an insight on these
kind of materials which they would give the highest priority for today’s and future developments. The results show clearly that silicon is still of highest importance today. Obviously the majority of the respondents still believe in the potential of silicon to solve material challenges in IMS / nano-electronics today. In the view of technological development it looks like the majority are remain in the current paradigm. There is hardly any indication on that stage, that actors look for fundamental changes or even see any pressure to substitute current materials more radically.

Figure 32 Materials and their attributes for IMS / Nano-electronics (left presence / right future)

Further potential is allocated to polymers and inks as well as compound materials. Amorphous materials, biomaterials as well as graphenes and gallium nitride do not show high importance today. No respondent selected Carbon hybrids. From a material perspective the results indicate clearly that the majority of the respondents remain today in a very traditional More Moore paradigm. Materials of importance for a paradigm-shift as biomaterials currently are not of high priorities in the point of view of the interviewees.

That rather traditional view on IMS and nano-electronics is also confirmed when the challenges are considered that go along with the technological attributes. The following figure shows the results.
Figure 33 Challenges related to current R&D in materials

Source: Technopolis

The Figure 33 indicates that the majority respondents perceive the properties of technological attributes as a major challenge in the handling of material as silicon, polymer and inks. The second most important challenge comes from the knowledge base (experience) in materials. In those materials with high potential for the future (e.g. Biomaterials, Gallium nitride) today lab capacity and handling is seen as major challenge in addition to properties.68

Expectations toward materials are slightly changing when analysing the results for future materials of high priority (Figure 34). Even so silicon and polymers remain of high importance a shift in priorities is taking place. Biomaterials, gallium nitride, and graphene are gaining importance. Obviously the respondents believe that the current silicon based paradigm is coming to an end. An alternative approach could be either a move towards new architectures and designs based on “conventional” silicon technology or new materials are needed in particular if there is a shift in the paradigm towards nano-electronics.

With the change in priorities on future materials the challenges going along with those materials is also changing when the future is considered.

68 Data results are consistent even if they are analysed for company and university respondents separately (see Annex 2.2)
Here more respondents perceive that in Biomaterials, Graphene and Carbon Hybrids with the growing importance also challenges towards properties, handling and knowledge base (experience) are increasing. Accordingly here respondents expect more R&D to be conducted to gain usability of those materials in IMS.

However, the respondents view reflects partly the current scientific hype on several materials, which are currently materials of interest. For example (CVD-) Diamond and carbon nanotubes were in the past also considered as “the material” for electronics and IMS in the future – in the case of diamond about two decades ago. However, reality was different in terms of electronic applications. Therefore, one can have seriously doubts to believe in materials like graphene. It can also be expected that this material will make a similar “career” like (CVD-)Diamond for electronic applications. The gap between the desire of a new material which has “perfect” electronic properties – which can be tailored during the fabrication process and which is at the same time compatible to standard silicon technology and has better “material properties” when compared with silicon – is not solved yet. Even, when this sounds like a “knock-out” criteria, it makes sense to have a focus on new materials with better material properties (e.g. diamond, carbon nanotubes, graphene) or cheaper processing capabilities (e.g. semiconducting polymers) which could at least serve for niche market applications. The current microelectronics and IMS arena is focusing on silicon due to the fact that it is definitely the best understood material with excellent processing capabilities, which were developed over several decades. From a European perspective it makes sense
to concentrate on high margin niche markets rather than on mass-market application in competition with Asia and up to now the USA where Europe is continuously losing ground. Some possible application areas were already mentioned before.

**Process technologies**
The results are not much changing if the **process technologies** are inquired. The following Figure shows the results.

Figure 35 Process Technologies and their Attributes for IMS / Nano-electronics (left today / right future)

Source: Technopolis

It is somehow surprising that no respondent has put a high priority on LIGA process technologies. Neither today nor in the future LIGA plays an important role in the perception of the respondents. The same is true for the imprint technology. Imprints might play a role as a tool for patterning. However it looks like the status in research needed to use imprints is not sufficiently reached. Going along with the existing paradigm CMOS gain highest priority among process technologies today followed by thick & thin film technology. That also indicates that actors mainly think within established paradigms.
The respondents express main challenges to technological attributes in R&D today. In the traditional paradigm of CMOS respondents quite similar to Thick-Thin-Film see the main challenges in knowledge, equipment, resources and lab capacity. Standardisation is hardly seen as a challenge as is regulations and self-assembling processes.

The results are not significantly changing when the future priorities are analysed (Figure 35 above). Based on a lower response rate the distribution remains quite stable.

The analysis of the highest challenges to those technological attributes gains some confirmation to the development of the technological variable. Even in the future in process technologies knowledge base, equipment and resources are perceived as main challenges.
The analyses of the technological variables and attributes as well as of the challenges faced by those show a high commitment in process technologies with the current paradigm and gives no indication on any future paradigm-shift. It looks like in process technology the current track in R&D show so many potentials that most of the respondents do not see any need for a shift in the technological paradigm.

In the near future – within the next 10 years – no revolutionary changes in processing technologies can be expected according to the relevant literature. This seems to be in agreement with the results from the respondents. However, the influence of process technologies - like nanoimprint lithography (from the survey results) - seem to be partly underestimated. A strong research base by commercial equipment suppliers and a wide range of possible applications making e.g. nanoimprint technology highly attractive for European actors.

**Design / Devices**

The picture is not much changing with design & devices technologies. In design / devices respondents do not give any indication for general changes in the paradigm.
Many respondents rank MEMS and silicon-based electronics highest on today. That goes along with the results above on materials that show also the strong importance of the current paradigm.

The analysis of the challenges on technological variables and attributes in design / devices shows that the knowledge base and resources are perceived as strongest challenges for today’s R&D. In the very established technological attributes MEMS and silicon based electronics IPR issues are also perceived as a strong challenge. In particular innovative SME seem to have problems in protection their IPRs against competitors. As the survey shows new modes of collaboration between SME and large enterprises might help to reduce the problem significantly.
In addition the availability of equipment is a problem for some respondents in MEMS. Here traditionally MEMS was frequently linked to developments in equipment for CMOS applications. However that combination is of limited use if the variety in technologies and materials increases and accordingly MEMS more and more requires specialised R&D trails that currently from an economic point of view are not sustainable.

The picture is not much changing when asking for the future in design / devices (Figure 39). The respondents give hardly any indication for future paradigm shifts in design / devices.

That becomes also quite obvious when the challenges in future R&D in design / devices are inquired.
Here the results of the survey do not indicate major changes. Still respondents perceive the knowledge base as well as resources as major challenges in the future.

Some possibly successful future devices like Memristors were presumably overlooked from the respondents of the survey. Memristors are nanoscale devices with a variable resistance and the ability to “remember” their resistance when power is off. Memristors could be used to build extremely dense computer memory chips that use far less power than today’s DRAM memory chips. Some researchers suppose that it seemed likely that Memristors might relatively quickly be applied in computer memories, but other applications could be more challenging. A number of partly very simple devices, which are fully compatible to standard silicon technology – this includes Memristors – do have the opportunity to be commercialized soon – within the next couple of years – as stated by Hewlett Packard.

**Software / Architecture**

A quite paradigm driven response is also shown by the results for software & architecture. Here also respondents do not indicate major changes.

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69 http://www.nytimes.com/2008/05/01/technology/oschip.html?em&ex=1209873600&en=3504fac701b97e4&ei=5087%0AMEMRISTOR
It is quite obvious from the survey that respondents weight software solutions for system integration fairly high. Instead of hardware solutions, software solutions show still potentials to adjust flexible to changing demands and to tailor made solutions. Accordingly, the respondents invest in those technological attributes. Based on software solutions for system integration, autonomy of actors, reliability, adjustability, and low failure ratios are perceived as advantages of higher investments in smart software.

Most respondents indicate that they concentrate today on R&D in multilevel and smart software. ASIC-IPs and analogue/mixed also play some role. However, that means that the technological attributes are still very much relying on “state of the art”-technologies.

That is also confirmed when looking at today’s challenges for R&D in software & architecture.
In multilevel modelling respondents see strong challenges in knowledge base, resources as well as available standards. That is at all not too surprising since standards are subject to impediments in software in general. The impact of IPR issues might result from various patent laws on software in various countries. Obviously here European actors see a challenge to maintain their IPR portfolio.

The importance of smart software in the future is increasing according to the respondents. The majority see highest potential in the smart software attribute of technological variables.
Figure 42 Challenges related to future R&D in software & architecture

Accordingly it is not surprising that the respondents expect an increasing challenge in IPR issues related to smart software. However, due to the growing importance of smart software knowledge base and resources followed by equipment is gaining larger relevance in the future.

Other “new” architectures like simple crossbar structures can simplify the layout and the processing of new devices. However, this approach – especially in combination with materials other than silicon – is currently research stuff and will need further research activities. It is remarkable that leading companies from the USA are working on that topic. If European companies do not want to lose ground more pronounced research activities in this area would be useful. However, not only the architecture and software would be of interest but the combination of these with new devices and new materials seem to be important. Some examples were already mentioned before.

**Power Supply / Connectivity**

The results show a strong importance for radio frequency transmission solution and energy storage for IMS / nano-electronics on today. Issues like energy storage and supply as well as the connectivity with other IMS are important problems many actors work on. That is not too surprising since the interaction among IMS is gaining more and more momentum to establish smart systems. In home automation as well as smart cities IMS have to interoperates to realise the benefits of their inter-linkage and need higher performances as well as extended functionalities.
At the same time the supply of energy to IMS is still not solved today. In particular in nano-electronics we face several problems in providing long-term energy.

It is quite interesting to note that none of the respondents has giving energy harvesting by energy scavenging or glucoses (e.g. with bio-fuel cells) any importance on today.

Figure 43 Power Supply & Connectivity and their Attributes for IMS / Nano-electronics

The results are also confirmed by the indication of the highest challenges in power supply / connectivity R&D.
Respondents perceive knowledge base, resources and equipment as major challenge to their R&D success. That is in particular true for battery and RF research as it is used for energy supply to IMS.

Standards do play a role as do IPR issues but of minor importance in the view of respondents.

That is just slightly changing by the perception of the respondents for the future (Figure 45) Here MEMS based energy-scavenging gains quite an importance. However, glucose as a source for power supply for implants still is not named by any respondent.
In the R&D for mems-based energy scavenging knowledge base, resources as well equipment provided highest challenges for R&D in the future. Mems based energy scavenging seems to be a major trajectory for future power supply and many respondents seem to rely on that particular technology.

Also here a number of scattered research activities can be observed worldwide. However, new power supplies will play a key role in advanced IMS in the future. Some needs for advanced power supplies were already mentioned in section 5.1.

5.4.2 Europe’s position in regard to their competitors in Asia, Japan and the US

In the survey the position of European actors in comparison to their global competitors has also been analysed. The main objective of the questions here was to identify areas where European respondents form companies and research labs perceive themselves as successful in the competition.

In regard to the application domains the respondents perceive in many areas as at least equivalent position of European actors. However, in the perception of the respondents there is hardly a competitive advantage of European actors that lead to a global advantage of European players. The study results show that in the view of the respondents the positioning of European actors is heavily depending on whom they compare with. Accordingly European actors in the sample seem to hold no position in any of the inquired application domains that gives them similar advantages as the US and Asian companies.
holds in computing in mass consumer markets. Accordingly the analysis has to dig deeper to identify in the globalised world in what application domains the European actors do have an advantage to whom.

Figure 46 Position of European actors in competition to the US (left today / right future)

In comparison to the US, European actors in the sample today perceive their advantage in mobility and partly in health. In both application domains they assume to maintain a strong position even in the future. In contrast to mobility and health European actors in the sample themselves do not see a strong advantage in the climate application domain. Even so the majority of the respondents indicate that they are at least able to compete with US actors a larger number of respondents saw the US in lead in opposite to those who saw Europe a leading position.

If changing from an application perspective towards technologies the survey results indicate that the European competitiveness is strongly declining in comparison to the US. In particular in Design / Devices Europe today in the perception of the respondents is hardly competitive.
The same results stand for process technologies as well as materials. In all these technologies the majority of the respondents perceive Europe’s position weaker than the US. However, in the future respondents expect Europe to catch up with the Americans in process technologies.

A quite similar picture fits for Japan. Results of the survey indicate an even stronger lead of Europe in the mobility application. In health there seems to be a quite similar competitive edge of European actors to Japan.
Looking in the future, many respondents indicate that Europe is catching up in health applications and maintains its strong position in the mobility application domain. A similar development is indicated for climate applications.

Looking at today’s technological position Europe’s in contrast to Japan the respondents perceive a lead of Japan in design / devices and process technologies. Europe is matching Japan’s competencies in software /architecture and power supply / connectivity.
In the future respondents expect an increasing competitiveness of European actors in design / devices as well as process technologies. Obviously here European actors catch up with their Japanese competitors.

The picture is strongly changing when looking at Asia excluding Japan. Here Europe today is still maintaining a strong position compared to Asian players. In all application domains inquired respondents see Europe in the lead. That is true for mobility, health as well as climate.
However the situation in applications is changing when looking in the future. Respondents believe that Asian actors catch up in climate and mobility applications in particular. In health applications the lead of Europe is declining but still prevailing.

The strong position of European actors in applications today is also confirmed by their position in technologies. In almost all technologies inquired European actors see their position better placed than that of Asian actors.
Similar to the trend in applications, Europe’s lead is under fierce competition by Asian actors in the future. Thus the survey indicates that in the future lose its lead in process technologies as well as in software / architecture. Just in materials the respondents see a chance for European actors to extend its competitive position.

5.4.3 Results of Interviews

The interviews focussed on four specific applications domains that were selected for an in-depth inquiry. The application domains are:

- **Health**
  - Monitoring: Self-monitoring and miniaturised diagnostics
  - Assistance: Ambient Assisted Living Technologies
  - Replacement: Artificial body functions
  - Prevention & Treatment: Individualised medicine and minimal invasive therapy

- **Climate Change**
  - Monitoring: Smart metering, exhaust identification etc.
  - Assistance: Smart House, smart car, smart infrastructure
- Optimization & Replacement: Smart grid, water control, HVAC control, combustion management
- Prevention & Treatment: Exhaust prevention, GHG prevention etc.
- Sustainable Production
  - Monitoring: Surveillance of energy & components
  - Assistance: Ubiquitous computing, maintenance assistance
  - Replacement: Tailored material surface
  - Prevention & Treatment: Waste control
- Sustainable Mobility
  - Monitoring: Infrastructure management, RFID logistics
  - Assistance: Driving assistance, public transport on demand
  - Replacement: e-mobility control, e-ticketing, battery management
  - Prevention & Treatment: Toll and e-tariffing

The evaluation of the interviews showed up that almost all interviewees work in more than a single application domain. Accordingly the results are clustered for various application domains and generate a cross-linked insight into the challenges of integrated miniaturised systems development today and in the future.

5.4.3.1 The main areas covered by integrated miniaturised systems in the application domains today

The interviews revealed a large usage of and potential for integrated miniaturised systems in all respective application domains. In the interviews the strong importance of integrated miniaturised systems for the technological development was thoroughly confirmed by all interviewees. Technically the interviews show that many experts see limits of the More Moore approach in integrated miniaturised systems. In particular down scaling is seen as a major challenge. However, there isn’t consensus among the experts; that nano-electronics and accordingly a further consequent miniaturisation-trend will be the path to solve these challenges.

Looking at trends in the selected applications domains it becomes quite obvious that in particular monitoring and assistance is already today a major playground for integrated miniaturised systems. There is a wide range of devices available and in use already today. That is true for mobility, health, climate as well as production.
Most experts believe that the next step will lead to larger usage of integrated miniaturised systems in treatments. In particular in health, mobility and climate application domains experts expect an extension of available integrated miniaturised systems to be used. It is strongly expressed that technologies for a larger use in treatments are in general available today and the major barriers do not come from technical problems.

Looking at the research conducted by the experts today many focus on design / devices, materials, process technologies as well as system building and software. In their research experts co-operate on national, European as well as international level. A pragmatic approach seems to dominate. As one interviewee stated: “We cooperate with those who are most suitable to meet our demands”.

5.4.3.2 Barriers and drivers on integrated miniaturised systems today

Looking at today’s technological barriers and drivers to integrate miniaturised systems a bundle of drivers have been identified by the experts. Most experts still believe in a certain technological determinism. Discoveries in materials in particular have the potential to lead to new developments in integrated miniaturised systems. Most experts see European actors fairly strong in material science. However, they fear that this strong position cannot be developed to a larger market share. Thus materials as the main driver of research are also seen as matching with a strong impediment in Europe. Furthermore experts name design / devices and power supply / connectivity as the major subjects in their research today.

In the view of experts in particular enhancement of reliability and standardisation is urgently needed to enhance Europe’s position in a global context.

In addition to these technological variables experts name the transition from the electro-mechanical components as well as increasing performance demands as drivers for their research.

A big debate among experts is also the expectation on the best path to follow in research. While some believe that the More Moore trajectory is still fruitful others are convinced that highest potential for European actors in integrated miniaturised systems are seen in More than Moore trajectories. It looks like the majority of the experts promote a larger integration in the More than Moore trajectory more than to invest in the battle on the best performances in the More Moore trajectory. So system integration in inquired application domains is seen as a major potential for European actors. As one expert stated as representative of a larger number of interviewees: “We need centralised design combined with decentralised production in flexible fabs to be prepared for the future”.

Integrated miniaturised systems 2020 and beyond
Among experts there is a strong agreement that the development of the complete value chain in Europe would be beneficial for the development of integrated miniaturised systems since the innovation process is heavily depending on the ability to link research and manufacturing.

5.4.3.3 Barriers and drivers on integrated miniaturised systems in 10+ years

The whole picture is not changing much when looking on the long run of 10+ years. Experts express a strong view on More than Moore research activities as well as system integration by 3D-packaging. The focus on new materials will prevail.

Asked for technological barriers and drivers experts perceive still strong opportunities in material sciences, followed by packaging technologies. Some experts even see driving power the More Moore trajectory. In particular scarcities in materials and energy will put a strong pressure on integrated miniaturised systems to find new solutions.

Barriers are seen in nano-micro-integration as well as the shrinking path by More Moore. Accordingly experts put an emphasis on research topics as simulation, search for increasing reliability, new materials and packaging technologies.

Even for the future several experts believe that Europe will be only competitive if the complete value chain is prevalent in Europe. With pieces in the value chain missing in Europe the experts fear that the new technological developments will not be turned into a business. With missing sections in the value chain companies in other markets as Asia or the US will appropriate the results of material research as well as of other research topics. To say it in other words: If manufacturing is not existing in Europe the gains from research are like to flow to those countries that host manufacturing.

5.4.3.4 Economic and societal barriers and drivers on integrated miniaturised systems

In the view of the experts the economic drivers and barriers are changing. In particular the old division between hard- and software is seen as more and more changing. New business models are in search that allows a combination of both. New business models are no more solely fab based but include services and value added services in the complete offer.

Going along with that change towards system integration the experts see a change with goes along with a little less concentration on miniaturisation on the one hand and a stronger interest in more individualised, more tailored components. It is not economies of scale of smaller and smaller components that set the future in the eyes of the experts it is enhanced functionality, stronger adjustments of components to single demands as well as a larger interconnectivity that will dominate future markets. Integrated miniaturised systems have to turn in the experts view in flexible systems instead at mainly
aiming at miniaturisation. Going along with that trend experts believe that a stronger focus on crosslinking among industries becomes more and more important. It is Europe’s competence to combine various industries to realise stronger effects by the integrated miniaturised systems. Good practice in cross linkage is the interaction between solar and semiconductor industry. Here strong economies of scope can be realised by the interaction.

On the application side in particular usage in sustainable energy, health and mobility is seen as promising areas for integrated miniaturised systems.

Going along with that turn in the development path the experts see a growing need for new enterprises and accordingly growing need for venture capital. In addition to that societal barriers and drivers are mainly seen in a technology scepticism in European societies going along with the impact of demographic change and a lack in the number of qualified human resources that also will hinder the development of the integrated systems of tomorrow.

Furthermore, the experts perceive the missing value chain sections in Europe as well as too little funding of international research projects with partners from non-European countries as an impediment in the development of integrated miniaturised systems in Europe. Here obviously exists a main challenge for European innovation policy to optimise the investment of public research in a optimal way.

5.4.4 Europe’s position in a global competition on integrated miniaturised systems

Looking at strong positions of European actors in integrated miniaturised systems expert interviewed in the study stated that in general in design / devices with a special focus on More than Moore, as well as in power supply / connectivity the European actors are competitive. Also software / architecture and materials are seen as strongholds of European actors. However the experts also indicate that the competitive position of European actors in material research is shrinking. From a technological perspective, Europe actors are less strong in areas as Power ICs and nano-electronic manufacturing. Accordingly the European actors are in particular strong in the B2B business whilst other regions are stronger in the B2C business.

In general, however, experts do not see European actors in weak position per se. They mainly question the European actors’ ability to commercialise their R&D results effectively and do ask for more creativity on the side of those using R&D results in Europe.

Accordingly experts are also asking for changes in the innovation policy. On the one hand a focus shift from technologies to application has to be promoted more strongly. Customers do not want technologies they want application that make their lives more pleasure full, safer and securer as well help them to save cost and energy. Accordingly, experts request a changing future research structure in Europe. Cross linkage among industries, stronger and more
application-focussed collaboration among research institutes and companies as well as business models that help to reduce time to markets are main proposals by the experts.

Going along with that a number of framework conditions have to be changed in the view of the experts. In particular the availability of venture capital is needed. Additionally more investments in standardisation are needed.

On the technological side more R&D in materials and process technologies is required to extend Europe’s competitive position. And last but not least the construction of the value chain has to be accelerated. In particular the establishment of a semiconductor industry in Europe for fabless business as well as a larger process technology industry is by several experts required.

5.5 Conclusions on technological developments
The empirical study on the technological developments was mainly driven by the interest in the actors’ activities in integrated miniaturised systems today and in the future. For selected application domains we have analysed what technological trends we can identify, that means, which portfolio of technologies for manufacturing IMS is available at all, and how actors in the field estimate their competitive position in a global context. Our empirical study on technological development was driven by the hypothesis that there might be an opportunity for a paradigm shift in integrated miniaturised systems. A paradigm shift takes place if actors change their definition of problems and their problem solving activities as well as strategies.

The hypothesis of a paradigm accordingly assumes that

4. A technological mainstream for the production of IMS exists

5. Efficient alternatives exist, at least in the R & D environment, which will be supplied from an existing technology portfolio

6. An incipient penetration of these alternatives already can be detected in the community

A change from CMOS to beyond CMOS can be assumed as an example for a possible paradigm shift that also goes a long with a new structure of the value chain accompanied by a reshuffling of the strength positions of global actors in the market. A paradigm shift therefore is a highly demanding change from the point of innovation and technology policy. It makes a change in the objectives of policy measures necessary, and the definition of impact indicators as well as the composition of actors integrated in such measures.

Although the picture is not completely consistent for all technological variables we can draw some general conclusions from our empirical work on technological developments in integrated miniaturised system:
1. From the survey and the interviews we can derive that the majority of the sample respondents see even in the future high potentials of the current paradigm based on down-scaling on CMOS pathway. That is true even so the empirical study on technological challenges and drivers shows that many experts are quite aware of likely limits of the More Moore approach in integrated miniaturised systems. In particular down scaling is seen as a major challenge. Based on that problem in miniaturisation, however, there is no consensus among the experts that nano-electronics and accordingly a further consequent miniaturisation trend will be the path to solve these challenges. On the one hand actors in the field still strongly believe in the potentials of the current paradigm; on the other hand they fear that the solving power of the paradigm is decreasing. That is the reason why there are so many approaches in R&D looking for alternatives.

2. We rather see as the overall result from the study and especially from the questionnaire that actors mainly think within the established paradigm. A radical move towards an application-approach of e.g. new materials, new nano-electronic devices, design and/or architecture could not be identified from the results of this study for any of the three application domains. That at least indicates that the majority of the representatives from firms are investing mainly in the developments going along with the current paradigm. This is certainly due to the fact that for the requested study period for 2015 + and the given premise of the necessary connection of the technologies used in selected applications only such technologies enter into commercial use (and because of the time-to-market can be), whose handling is known and familiar by the companies.

3. That result is also confirmed by the fact that the majority of the questionnaire respondents see a high potential for technological developments in multilevel developments and more important in smart software\textsuperscript{70}. Instead relying on hardware developments in integrated miniaturised systems obviously several actors perceive higher returns from changing the software used in the integrated miniaturised systems.

4. Even so the majority of the respondents show faith in the existing paradigm a noticeable number of respondents of the questionnaire believe that the current silicon based paradigm is showing limitations. We could identify two directions in their search process for alternatives. Some see high potentials in new materials in particular if there is a shift in the paradigm towards nano-electronics based on a More Moore approach. Alternatively other actors see high potentials in a move towards new architectures and designs partly based on “conventional” silicon

\textsuperscript{70} Smart Software means Efficiency, Modularity, Fault-Tolerance, Intrinsically Safety, Re-Usability, Ease to use
technology (e.g. GaN on silicon) to reach progress and to increase the performance of IMDs.

5. Furthermore the results of this study indicate a strong importance for connectivity, preferably with radio frequency transmission solutions and for energy storage, harvesting and management as key knowledge for today’s and even more future integrated miniaturised systems. Issues like energy storage and supply as well as the connectivity with other integrated miniaturised systems are important R&D challenges many actors work on.

Looking at the competitive position of European players in integrated miniaturised systems it is to state that Europe is quite good positioned in many application domains. The technological position of Europe is however a bit different. The following conclusions can be drawn:

1. It looks quite convincing from the empirical data that Europe in general is able to compete globally on applications using integrated miniaturised systems. In particular today Europe is leading edge in mobility applications and partly in health applications. That is true in comparison to the US and Japan. The European position is even stronger compared to Asia (without Japan). Looking in the future, many experts indicate that Europe is catching up in health applications and maintains its strong position in the mobility application domain compared to the US and Asia including Japan. A similar development is indicated for climate applications, mainly concerning issues of harvesting, storage and delivery of renewable energy. These domains most likely do have important business relevance for the European players. The analysis, however, also indicates that in particular Asia (without Japan) is catching up with Europe. Accordingly several experts assume that Europe is in danger to lose it leading positions.

2. In technologies for integrated miniaturised systems Europe is less strong than in applications. It also is more heterogeneous depending on the region we are looking at. In particular compared to the US European players are less well equipped than their US counterparts. In particular in power supply/interfaces technologies and process technologies the US is in a strong lead. That is also true for software / architectures, even so the lead here is smaller. In comparison to Japan European players still are seen as strong in design/devices, process technologies and software. In comparison to the rest of Asia Europe is still in lead in most technologies inquired. However looking at the future the picture is changing. The rest of Asia is catching up in high speed. Additionally the experts assume that Europe is losing ground compared to Japan. Just in comparison to the US experts expect Europe catching up in process technologies.

The empirical study also provides an insight in drivers and barriers to the development of integrated miniaturised systems.
1. Looking at today’s technological barriers and drivers to integrate miniaturised systems a bundle of drivers have been identified by the experts. Most experts still believe in a certain technological determinism. Discoveries in materials in particular show the potential to lead to new developments in integrated miniaturised systems. Most experts see European actors fairly strong in material science. For technological barriers and drivers experts perceive still strong opportunities in material sciences, followed by packaging technologies, which is at least partly related to each other.

2. In the view of experts in particular main barriers are generated by a lack in the existing knowledge base in Europe, the human resources available and lacks in equipment. Further barriers identified by the experts result from necessary enhancements in reliability and standardisation are needed to strengthen Europe’s position in a global context.

The empirical study does also show some results toward more general barriers and drivers. Those are primarily aiming at the infrastructure in Europe. The following points have been raised:

1. For the future several experts believe that Europe will be only remain competitive if the complete value chain is prevalent in Europe. With pieces in the value chain missing in Europe the experts fear that the new technological developments will not be turned into business, at least not in Europe. Experts demand for a changing future research structure in Europe. Cross linkage among industries, stronger and as more application-focused collaboration among research institutes and companies as well as (new) business models that help to reduce time to market span are main proposals by some experts.

2. That picture is also enhanced by the fact that several respondents see the value of new approaches in the technology variables as mainly restricted to specialized solutions, which can serve for niche market applications. Hardly any of the respondents gave an indication of a new paradigm on the hardware sight that lead to a mass market. This result is in particular of interest for the question how much of the value chain in integrated miniaturised systems shall be present in Europe. Some actors in particular from the equipment industry have mentioned that they do not see a need for hosting the complete value chain in Europe whilst others have main concerns with the white spots in the European value chain in integrated miniaturised systems.
6. Conclusions and recommendations

The report has covered a vast area of topics and aimed to assess the future challenges and opportunities for research on integrated miniaturised systems. The study has worked on future trends in integrated miniaturised systems from various angles. Thus the study brings together several perspectives, that each provides a better view on the requirements for future integrated miniaturised systems:

- The perspective of the **societal challenges** that have influence on the (re-) shaping of markets and business models of both the nano-electronics and application industries (Chapter 2)

- The perspective of **market developments**, particularly in those industries that have ICT based products and services in a range of markets, thus the ‘application industries’ but also in the nano-electronics industry (Chapter 3)

- The **scientific and technological perspective** which builds on existing strengths in competencies and technologies in the EU, particularly in the electronics industry, research centres and universities (Chapter 4)

6.1 Conclusions

Quite a number of conclusions can be drawn from our study.

The study shows that the grand societal challenges form an important driver for research, development and innovation in the field of IMS. They have a guiding effect on R&D activities in the domain of IMS both for companies and research institutes. In turn, IMS offers promising applications that deal with societal challenges, which are specified below.

- **Health and Ageing** deals with the ageing populations and associated challenges to the health system. Entrance points for applications of IMS are quick and easy (integrated) diagnostics tools; applications for minimal invasive therapy; and assisted living of elderly and patients.

- **Climate change** puts limitations to our consumption pattern, especially of our energy production and use. Promising applications of IMS include: renewable energies, notably solar and wind power; and smart grids including smart metering.

- **Sustainable production** deals with optimising the efficiency of production processes, or development of new production methods with higher efficiency with regard to energy and (scarce) material use. Interesting applications of IMS contribute to higher supply chain and logistics efficiency in production processes, as well as flexible and adaptive production processes, intelligent machinery and zero-defect production.
Sustainable mobility deals with all aspects of mobility that currently impact our environment, our living conditions as well as the economy. Important solutions IMS offer are applications for advanced driver assisting systems and new or improved propulsion systems.

Based on identified grand societal challenges and their impact on society, the first spotlight in the study was set on identifying application domains of high relevance for both, the handling of the grand societal challenges and the future trends in integrated miniaturised systems. Based on empirical inquiries the study’s scoring system was able to show that in particular the following application domains meet the requirements. These application domains are:

- Applications that enable smart metering, control and sensing in combination with smart grids (Climate Change)
- Miniaturised self-monitoring for personal use and miniaturised diagnostics or monitoring devices for professional use (Healthy Ageing)
- Advanced driver assistant systems in combination with real-time multi-modal transport information systems for individual users to optimise transport mode and route selection. (Sustainable Mobility).

These application domains show a high ability to contribute to the solution of problems initiated by the grand societal challenges. They also show high economic potential for European players. The competitive position of European players acting in these application domains is fairly strong as is the systemic complexity of technological and economic approach.

The empirical study clearly indicated that all three application domains are challenged by high demands on applied research and the developments of demonstration and pilot installations. That makes quite sure that the majority of the experts consulted do not see a need for fundamental research results but are more concerned on those research results that reduce time to market and enhance the usability of the applications generated in the application domains.

It is, therefore, hardly surprising that experts perceive inadequate business models and economic risks as major barriers to the successful placement of applications on the market. Furthermore the lack of private as well as public research funding is tagged as a barrier.

Furthermore, the context of uncertainty and the lack of product and production standards in nano-electronics, but also market fragmentation and lack of economies of scale and limited production numbers, act as barriers. System integration seems the answer for small actors in the sector to address market needs. This asks for extensive planning of production, and collaboration in innovation. Another important factor is increased funding opportunities to bridge the valley of death in order to get applications on the market. The main challenges for the introduction of IMS applications are related to applied research and pilots. Moreover, more research is needed on
the cost-effectiveness of new applications, especially for medical devices the added value of new devices is not clearly known.

The importance of the micro- and nano-electronics industry for Europe is undisputed and the market potential high. Europe has been able to maintain strengths in a number of key applications, with leadership in radio-frequency (RF), analogue/mixed signal and More than Moore technologies. An important future challenge, however, is to maintain its built-up advanced manufacturing capabilities. Europe’s leading position in these domains appears primarily to be related to the presence of strong existing ecosystems, in which OEMs, innovative SMEs and public research organisations are still able to develop innovative solutions. Whether current Europe’s competitive advantage in these areas can be maintained and expanded in the long term depends on an important extent on whether these eco-systems can be maintained.

The in-depth analysis of the technological requirements necessary to meet the demand by the application domains, has shown that a majority of the respondents to this study (both from surveys and interviews) still act in the current CMOS-based paradigm with a strong view on downsizing (More Moore). Many of the IMS stakeholders see the limits of the CMOS-based More Moore approach. However, there is still a strong belief in the future problem solving capacity of the paradigm.

All tested indicators for a shift of the paradigm towards a beyond CMOS approach and/or a More than Moore approach, hardly show any significant numbers. Looking at the developments in the current paradigm, the study indicates that players in the field are trying to maintain their position in the current paradigm as long as possible.

The study shows that European actors have a strong competitive position in the health and mobility application domains. In these application domains they can compete with competitors in Japan and the US. However, the expectations of the respondents towards the future competitive position of European players in the field has indicated that they are in danger to lose ground compared to other regions worldwide.

Notwithstanding the competitive position of European players in health and mobility applications, on the technological side Europe - according to our empirical analysis - already today lacks behind the US and partly Japan. In particular in power supply / connectivity technologies, software/architecture and process technologies European players lag behind their US competitors.

The study shows that materials and integration technologies (connectivity, packaging etc.) show highest potential for a paradigm shift towards beyond CMOS and/or More than Moore.
The study has identified general shortcomings in the existing knowledge base, the access to human resources as well as a lack in equipment.

A highly controversial topic in study is the composition of the IMS value chain. It is quite clear from the study that currently not all elements of the value chain for integrated miniaturised systems are present in Europe. Parts of the value chain are dominated by Asia and/or the US. There are quite a number of respondents, especially from the semiconductor industry, that fear future innovations of European players will not lead to economic wealth since they are used in other regions where they generate value added. On the other hand, in particular respondents from the equipment industry, do not see any need for STI policy to fill the gaps in the value chain as long they have access to the supply chain.

More than Moore and beyond CMOS are in need for a new set up of the value chain and the value production in the value chain. Traditional CMOS components are not feasible to establish a full range of More than Moore and beyond CMOS devices.

6.2 Recommendations

The study has been commissioned by DG INFSO to help the Commission to develop Horizon2020 and in general its support to IMS beyond 2015.

1. Our study suggests that the European Commission should maintain a considerable share of its research and support for evolutionary innovations in the More Moore paradigm. Innovations in that paradigm will generate wealth within the next decade.

2. If STI policy wants to enhance the likelihood for a paradigm shift towards More than Moore and/or beyond CMOS they have to overcome the penguin effect towards a new paradigm. Nobody wants to be the first making the jump because of the fear to lose the game. To reduce the penguin effect STI policy has to establish safe “playgrounds” on which new paradigmatic devices can be explored. Given the importance of the Grand Challenges, these playgrounds could be encouraged through demand led policies such as public procurement of innovation and setting standards that help to generate innovations.

3. Taking the three application areas as representative for all promising application domains for IMS, the Commission should consider implementing instruments that allow the development of pilots, demonstration projects and business models to gain critical mass for market entrance and enhance the usability to the applications generated in the application domains.
4. The Commission should support and facilitate the gathering of strategic intelligence to map and analyse the (potential) value chains in the emerging areas of More than Moore and beyond CMOS. These exercises can help the current IMS stakeholders to develop cross-sector linkages with other European actors or it can guide policy makers to encourage emerging ventures in the ‘white spaces’ thus encouraging a smart specialisation based on IMS as a General Purpose Technology.

5. When promoting a paradigm shift, the Commission should carefully design its measures to avoid early lock-ins in new paradigms that are inferior in the long-term to competing paradigms in the outset. This means that the measure should promote variety in approaches in the future.

6. The study shows that materials and integration technologies (connectivity, packaging etc.) show highest potential for a paradigm shift towards beyond CMOS and/or More than Moore. To establish this new paradigm, the Commission should focus their instruments and programmes on stimulating collaboration between industry and research (universities) to establish a knowledge base, and create human resources and equipment needed.
Appendix A Our methodology in detail

A.1 General methodological approach of the study

The team has undertaken the following activities:

**Inception phase:** writing the inception report, first desk research. The European Commission approved the report.

1. Identification STEP trends and challenges, features of application domains, technological strengths and weaknesses in Europe

   iii) Identification of societal challenges: healthy ageing; climate change; sustainable mobility; sustainable production

   iv) Identification of promising (trends in) application domain and some applications of interest relating to the 4 grand challenges

   v) Identification of promising technologies (and trends) relating to the application domains of the grand societal challenges

We have used a methodology that started from the Grand Challenges, and we derived future visionary applications domains and applications from these analyses. Moreover, we have looked at the technological as well as the industrial requirements needed to establish the identified applications. First, we have tried to analyse the trends set by the grand challenges and their (potential) impacts by means of a literature survey. Examples of criteria used for the trend analysis for healthy ageing for instance are: Numbers on the age composition of elderly; Numbers on health cost going along with aging societies; Numbers on care situation of elderly people; Numbers on employment of elderly, et cetera.

The identification trends and drivers within the Grand Challenges provided the basis for searching for promising applications domains and markets. In order to identify promising applications domains and markets the consortium conducted a document and literature survey. The aims of the literature study were twofold. The first goal was to find possible applications that would help solve problems or challenges posed by each GC. The second main goal of the literature overview was to find evidence concerning market potential of these applications.

The consortium analysed several types of documents. In order to find future applications domains, the consortium focussed the document search on foresight, forecasting and scenario studies, about future technologies, the Grand Challenges and specific markets. Annual reports of companies in some case provide an outlook to future products and markets as they often
reveal company strategy. We analysed annual reports of some of the major companies in different application markets. The third main source includes documents that deal with future policy, action or research plans and innovation agenda’s.

Although the study focus is on promising application domains for EU microelectronics sector, market potential can be worldwide. In the documents search we tried to find evidence of worldwide market potential. Market potential data on future applications are often not available, as markets for new products are highly uncertain. However, often data can be found that can give an indication of the market potential. Examples are (the contribution to) cost reduction possibilities, current and future expenditure, or investment on certain issues or problems, or economic costs and benefits of problems and measures to solve these problems. The data gathered will now be further shaped and clustered in order to make a further selection of application domains and applications.

Finally, we’ve also already looked at the **technical components** to realise some of the application domains identified in the previous step. However, since the definition and prioritisation of application domains and application is work in progress, the technological analysis had the primary objective to scan the technological trends and challenges. It is the main objective of the step to identify what technological developments will come up in the near future till 2020, and what technological requirements are in place to realise the selected applications.

Based on that analysis and scoring the impact of the technologies on the use in the applications identified has to be analysed. Here it is of highest importance to identify the political actions to be considered to enable the technologies to be ready in time for the use in the applications identified. This will be a focus for the next part of the study.

2. **A first SWOT analysis of the current strengths in the electronics industry** (promising industries)

A first SWOT analysis has been made of the semiconductor industry, international and focused on Europe. A first scan has been made of the competitive position of this industry, including an overview of promising markets and/or applications, and the growth potential. Furthermore, a summary has been made of Europe’s competitiveness of several sectors (potentially) interesting for miniaturised systems.

3. **Interviews.** The interviews were conducted by team members of Technopolis, SEOR and VDI/VDE-IT. The target group for the interviews were scientist in universities and research institutes, employees in R&D departments as well as application managers in companies. Furthermore visionary thinkers have been interviewed.
The final interviews were focussed on three application domains. For these the interviews covered a wide range of topics to explore the developments in those application domains. Data was collected for today’s work in integrated miniaturised systems in the application domains as well as for their prospective work in 10+ years. In particular the interviewees were asked to give information on their current work in integrated miniaturised systems, the barriers and drivers they face today as well the position of European players in their field in a global competition.

A similar set of questions has been asked for the period of 10+ years. Finally the interviewees were asked to give their view on innovation policy instruments that would help Europe to gain a stronger position in the global competition. The interviews have been recorded by summarising written reports that were subjects to the data evaluation. In the evaluation of the data is has been noticed that many of the interviewees are working in various application domains. Accordingly the results had been clustered and been used to developed typologies of responses to the current and future demands on integrated miniaturised systems in the various application domains.

The following experts have been interviewed:

**Figure 52  List of interviewees**

<table>
<thead>
<tr>
<th>Name</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beenker, G.</td>
<td>NXP, CTO.</td>
</tr>
<tr>
<td>Bertollini, Dr. R.</td>
<td>WHO, Chief Scientist WHO-EU</td>
</tr>
<tr>
<td>Chabli</td>
<td>CEA LETI. Director Research</td>
</tr>
<tr>
<td>Chataway, J.</td>
<td>RAND Europe, Director Innovation and Technology</td>
</tr>
<tr>
<td>Domann</td>
<td>ASML, VP MST</td>
</tr>
<tr>
<td>Fecht</td>
<td>Director of the Institute of Micro- and Nanomaterials, University of Ulm</td>
</tr>
<tr>
<td>Hartman, R.</td>
<td>ASML, Public Affairs/Lobbyist</td>
</tr>
<tr>
<td>Helleputte, J.</td>
<td>IMEC</td>
</tr>
<tr>
<td>Hobbs, L.</td>
<td>Head of Research</td>
</tr>
<tr>
<td>Hofstraat, H.</td>
<td>Vice President Philips Research</td>
</tr>
<tr>
<td>Hoeger, Reiner</td>
<td>Director Engineering Governance and head of innovation Continental</td>
</tr>
<tr>
<td>Johnston, C.</td>
<td>University of Oxford</td>
</tr>
<tr>
<td>Kaesmaier</td>
<td>LFoundry GmbH, VP Research</td>
</tr>
<tr>
<td>Karl, M</td>
<td>Carl Zeiss</td>
</tr>
<tr>
<td>Kosch</td>
<td>X-Fab, CTO</td>
</tr>
</tbody>
</table>
4. **Survey 1:** One of the main aims of the first survey was to identify key application domains where Europe is strong and which could greatly benefit from a largely improved capability to produce advanced Nano-electronics systems. Important selection criteria for the key application domains are their impact on society, industry and research. Out of the long list of application domains found, the survey aimed to identify a few key applications. The survey was conducted among the wider European stakeholder community in the nano-electronics domain, but also in possible application domains. In this survey we asked respondents to rank the different applications on five different aspects. These aspects are the
impact on society, the impact on economic growth and competitiveness, the systemic complexity of the applications, the current position of the European industry in the application domains and finally, user acceptance risk. With impact on society we mean the contribution of the different applications to provide products and services that help solve the four Grand Challenges.

We established a database of 1938 respondents. Respondents of this survey came from a wide variety of sources. The most apparent sources are participants from FP6 and FP7 projects related to ICT and nanoelectronics that have a link with one of the four Grand Challenges. Other sources are conference participants and participants of matchmaking events related to the Grand Challenges. In the search for respondents we tried to make sure that we have a similar amount of respondents for each grand Challenge. Some respondents, can be linked to a single Grand Challenge, especially for health and ageing and sustainable mobility. For climate change and sustainable production it is more difficult to link people to a specific Grand Challenge.

We sent an invitation to 1938 possible respondents. Most invitations were sent to people involved in climate change and sustainable production, partly because the range of companies involved is wider for these Grand Challenges. Out of the 1938 invitations, 314 respondents started the survey. A total of 263 respondents finished the survey. This mean we achieved a response rate of 16% to 14%. This response rate is sufficient to compare the outcomes of the survey for each Grand Challenge. Most respondents (152) are from universities (34), or private (36) and public research institutes (77). 62 respondents are from Manufacturing companies and 54 respondents are from Engineering and consultancy firms. The remaining 46 respondents are from other organisations. Within manufacturing companies the main respondents are people from general management (14) and R&D (32). Respondents in research, engineering and consultancy are mostly from general management (65). Other main respondents function categories are department leaders (50), researchers (50), or consultants (33).

All European countries are represented in the survey. The largest shares are from Belgium (14.7%), Spain (12.5%) Italy (11.5%) and Germany (10.3%). Other countries that have a large share are the United Kingdom (6.4%), the Netherlands (5.8%), Sweden (4.8%), France (5.1%) and Finland (4.2%).

5. Survey 2: The survey was designed as an online survey based on closed and semi-open questions. The closed questions offered the respondents alternatives that had been selected from the results of the secondary analysis of the technological developments in integrated miniaturised
systems. The survey was send on October 19, 2011 to more than 3,000 candidates that had been derived from various sources. The selection criteria for the respondents were their involvement in integrated miniaturised systems as well as in nano-electronics alternatively. More precisely: The data on respondents' had been collected by analysing the existing team databases, information on conference participation as well as other sources.

The main objective of the survey was to generate data to test the hypotheses developed as a result of the secondary data analysis. Accordingly, the survey has been structured as a funnelling approach.71 Beside general information on the respondents those have been funneled from more general questions aiming at the respondents main application domains towards specific competencies and technologies that are seen by the respondents as major drivers or barriers to technological development.

In the survey respondents were asked to select two main application domains out of three options. They got an option to indicate an open application domain if none of the proposed three application domains has been matching with their main fields. For each of the two selected application domains the whole set of questions had to been answered. The questions have been divided in those questions aiming at technological specifications (variables and attributes) as well as those aiming at the positioning of European actors in those technologies identified by the respondents as important. The structure of the survey as well as the links among the various questions is illustrated by the following Figure.

---

71 See appendix # for the design of the survey
As is shown by the Figure respondents had to answer twice for current as well as for future challenges and drivers that might have an impact on IMS and nano-electronics.

In computing survey’s results we have always clustered responses from the first and second cycle if the total number of responses was below a normal distribution. For statistical reasons that is necessary to get valid results.

6. Patent study: The study has already started to analyse the development in technologies of interest for integrated miniaturised systems and conducted a patent analysis that helps to define the horizon of technological opportunities.

A.2 Methodological and statistical information on Survey 2

The team members of Technopolis, SEOR and VDI/VDE-IT with support by Matthias Werner from NMTC conducted the interviews. The interviews were conducted by interview questionnaires that were harmonised as much as possible. The target group for the interviews were scientists in universities and
research institutes, employees in R&D departments as well as R&D or application managers in companies. Furthermore visionary thinkers were interviewed.

The interviews were focussed on three application domains. For these the interviews covered a wide range of topics to explore the developments in those application domains. Data was collected for today’s work in integrated miniaturised systems in the application domains as well as for their prospective work in 10+ years. In particular the interviewees were asked to give information on their current work in integrated miniaturised systems, the barriers and drivers they face today as well the position of European players in their field in a global competition.

A similar set of questions was asked for the period of 10+ years. Finally the interviewees were asked to give their view on innovation policy instruments that would help Europe to gain a stronger position in the global competition. The interviews have been recorded by summarising written reports that were subjects to the data evaluation. In the evaluation of the data it was noticed that many of the interviewees are working in various application domains. Accordingly the results were clustered and used to developed typologies of responses to the current and future demands on integrated miniaturised systems in the various application domains.

A.2.1 General Survey Results

432 persons answered the survey. With 178 respondents companies are represented as a major group in the sample. 107 respondents work for universities. The remaining participants are either in public or Non for Profit research institutes. Private research institutes are also represented in the sample.
In the sample 27 respondents did not state their organisation. Accordingly it is not known what organisation they are belonging to. These respondents have not been taking into account whenever the data was analysed in respect to organisational or professional backgrounds.

The sample represents a variety of professional backgrounds. The strongest number of respondents acts as leaders of departments. However, the share of researchers, consultants and other managers is also well represented by the sample.

Source: Technopolis
At the outset of the survey the respondents were asked to state their involvement in integrated miniaturised systems and nano-electronics. The sample shows that about 51% of the respondents are actively involved in IMS and nano-electronics while the rest is not involved yet.

Accordingly 218 out of 430 respondents work in the field and are subjects to our main inquiries. The 430 respondents include those who did not give any information on their professional status.

Based on those who gave information on their professional status the majority of respondents who are active in IMS come from private companies, followed by universities and research institutes.
In the sample those companies who will invest in IMS /nano-electronics in the future is smaller than those who have no plans. Same is true for all kinds of research institutes.

The in-depth analysis focused on three application domains to inquire main drivers and barriers to IMS and nano-electronics. Those application domains are

- Diagnostics or monitoring devices to personal or professional use (Healthy aging)
- Applications that enable smart metering, control and sensing for smart grids (Climate change)
- Advanced drivers assistant systems and /or real-time transport information systems for individual use and transport optimisation (Sustainable mobility)

As has been stated above the respondents were asked to select their main application domain for today as well as in a second round for the future. The following Figure shows results for the current activities of the respondents in the selected application domains.
The majority of respondents represent the health sector. Almost 40% of the respondents work in the health industry or do research in the health area. Those are followed by the number of respondents who are associated to the mobility sector (about 24%) and those in the climate sector (about 14%). In the sample there is a significant number of respondents who do not work in the three applications areas selected (about 24%). Among those are several who indicated in the open answer that they are working for organisations that are involved in enabling technologies as microelectronics and sensors.

If we look at the future the results are changing slightly. The following figure shows that still in the future respondents prioritise the health application highest (about 40%). The result is slightly influenced by the larger number of respondents from the health sector in the sample.
Mobility and climate application domains have swapped. For the future about 23% of the respondents rank the climate application domain higher than the mobility application domain (about 19%). About 19% of the respondents see none of the options as of highest importants in the future.

Based on the results on application domains the respondents answered what technological variables and attributes they give a high priority for the application domain. The term technological variable stands for various technological alternatives that can be used in IMS and nano-electronics. The respondents could choose out of the following technological variables:

- Materials
- Design / Devices
- Process technologies
- Software / Architecture
- Power Supply / Connectivity

In the survey the respondents were asked to indicate two out of 5 variables per application domain today and in the future where they will see highest priorities. Based on their selection they could further specify the attributes of the variables they have chosen. The following attributes were options:
Figure 60 Technological Variables and their Attributes

With the combination of technological variables and their attributes the respondents have provided information on their main technological activities in IMS / nano-electronics.

For the analyses of the technological variables and attributes that will drive or block the IMS and nano-electronics today and in the future in the application domains only those respondents were taken into consideration that marked their involvement in any of the application domains. Accordingly the numbers are quite lower than represented by the total sample.
A.2.2 Additional figures with link to the text in chapter 5.

Figure 61 Technological Variables and their Importance in Application Domains Today (left) and in the Future (right). Data for company respondents.

Source: Technopolis

Figure 62 Technological Variables and their Importance in Application Domains Today (left) and in the Future (right). Data for university respondents.

Source: Technopolis
Figure 63 Materials and their attributes for IMS / Nano-electronics (left presence / right future). Data for company respondents.

Source: Technopolis

Figure 64 Materials and their attributes for IMS / Nano-electronics (left presence / right future). Data for university respondents.

Source: Technopolis
Figure 65 Process technologies and their attributes for IMS / Nano-electronics (left presence / right future). Data for company respondents.

Source: Technopolis

Figure 66 Process technologies and their attributes for IMS / Nano-electronics (left presence / right future). Data for university respondents.

Source: Technopolis
Figure 67 Design / Devices and their attributes for IMS / Nano-electronics (left presence / right future). Data for company respondents

Source: Technopolis

Figure 68 Design / Devices and their attributes for IMS / Nano-electronics (left presence / right future). Data for university respondents.

Source: Technopolis
Figure 69 Software / Architecture and their attributes for IMS / Nano-electronics (left presence / right future). Data for company respondents.

Source: Technopolis

Figure 70 Software / Architecture and their attributes for IMS / Nano-electronics (left presence / right future). Data for university respondents.

Source: Technopolis
Figure 71 Power Supply / Connectivity and their attributes for IMS / Nano-electronics (left presence / right future). Data for company respondents.

Source: Technopolis

Figure 72 Power Supply / Connectivity and their attributes for IMS / Nano-electronics (left presence / right future). Data for university respondents.

Source: Technopolis
Appendix B Survey 1 results

We established a database of 1938 respondents. Respondents of this survey came from a wide variety of sources. The most apparent sources are participants from FP6 and FP7 projects related to ICT and nano-electronics that have a link with one of the four Grand Challenges. Other sources are conference participants and participants of matchmaking events related to the Grand Challenges. In the search for respondents we tried to make sure that we have a similar amount of respondents for each grand Challenge. Some respondents can be linked to a single Grand Challenge, especially for health and ageing and sustainable mobility. For climate change and sustainable production it is more difficult to link people to a specific Grand Challenge. The table below gives an overview of the response characteristics.

Figure 73 Characteristics of respondents

<table>
<thead>
<tr>
<th></th>
<th>respondents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invitations sent of which:</td>
<td>1938</td>
<td></td>
</tr>
<tr>
<td># invitations to send to people beforehand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>known to be involved in:</td>
<td></td>
<td></td>
</tr>
<tr>
<td># invitations to people involved in SM</td>
<td>329</td>
<td></td>
</tr>
<tr>
<td># invitations to people involved in SP (also</td>
<td>635</td>
<td></td>
</tr>
<tr>
<td>links with HA, SM and CC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td># invitations to people involved in CC (also</td>
<td>771</td>
<td></td>
</tr>
<tr>
<td>links with SM and CC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td># invitations to people involved in HA (only</td>
<td>548</td>
<td></td>
</tr>
<tr>
<td>HA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td># respondents who clicked link survey</td>
<td>334</td>
<td>17%</td>
</tr>
<tr>
<td># respondents who answered first question</td>
<td>314</td>
<td>16%</td>
</tr>
<tr>
<td># respondents who completed the survey</td>
<td>263</td>
<td>14%</td>
</tr>
</tbody>
</table>

Source: SEOR

We sent an invitation to 1938 possible respondents. Most invitations were sent to people involved in climate change and sustainable production, partly because the range of companies involved is wider for these Grand Challenges. Out of the 1938 invitations, 314 respondents started the survey. A total of 263 respondents finished the survey. This means we achieved a response rate of 16% to 14%. This response rate is sufficient to compare the outcomes of the survey for each Grand Challenge.

Most respondents (152) are from universities (34), or private (36) and public research institutes (77). 62 respondents are from manufacturing companies and 54 respondents are from Engineering and consultancy firms. The remaining 46 respondents are from other organisations. Within manufacturing companies the main respondents are people from general management (14) and R&D (32). Respondents in research, engineering and consultancy are mostly from general management (65). Other main
respondents function categories are department leaders (50), researchers (50), or consultants (33).

All European countries are represented in the survey. The largest shares are from Belgium (14.7%), Spain (12.5%) Italy (11.5%) and Germany (10.3%). Other countries that have a large share are the United Kingdom (6.4%), the Netherlands (5.8%), Sweden (4.8%), France (5.1%) and Finland (4.2%).

Half of the respondents say they do apply Integrated Miniaturised Systems (IMS) and/or nano–electronics in their research, products or services. Manufacturing companies, Universities and public research institutes are more inclined to apply IMS in their research, products or services. 64% of the respondents from public research institutes say they apply IMS, Universities in 59% of the cases and 57% of the respondents from companies say they apply IMS. The share of respondents who use or apply IMS is lowest in respondents active in Climate change (39%) and highest in Health and Ageing (66%). the shares a more equal for sustainable production (49%) and sustainable mobility (44%).

Most respondents (31.8%) that currently do not apply IMS think that it is possible that they will use in the future. 13.5% of the respondents think it is probable and 6.1% think it is very probable that they will use IMS in the future. More than 48% do not know or think that they will probably not, or very probably not use IMS.

Respondents were asked if they were active in each of the Grand Challenge and in which Grand Challenge they see most opportunities for their organisation (in terms of new products, research). The shares of the respondents are quite similar between the Grand Challenges, except for sustainable mobility. This is shown in table 1.

For each grand challenge we established a list of applications. We let respondents choose which list of applications they would review. The main reason is to make sure that respondents would review the applications with which they are most familiar. Organisations can be active in all Grand Challenges and the Grand Challenge that provides most opportunities for the organisation does not have to correspond with the expertise of the respondent. In turned out that in fact many respondents answered differently to both questions.

Most organisations in our survey are active in the field of Climate change (58%) and sustainable production (49%), 45 percent of the organisations is active in health & ageing, while 44 percent is active in sustainable mobility. Sustainable production provides most opportunities for the organisations according to 28% of the respondents, followed by health & ageing (25%). Climate change is most promising for 20% of the respondents, while sustainable mobility provides most opportunities for 15% of the respondents.
Most opportunities for health & ageing are identified by (manufacturing) companies and public research institutes. Opportunities in sustainable mobility are most important for engineering & consultancy firms and (manufacturing) companies. Climate change provides most opportunities for universities, public research institutes and engineering & consultancy firms. Sustainable production provides most opportunities for public research institutes and (manufacturing) companies.

The shares of respondents that choose a specific Grand Challenge are divided quite even, except again for sustainable mobility. The answers given to the three questions are shown in the table below.

Figure 74 Overview of respondents for each Grand Challenge

<table>
<thead>
<tr>
<th>GC</th>
<th>Active in a GC</th>
<th>% most opportunities of active companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change</td>
<td>169 58%</td>
<td>34%</td>
</tr>
<tr>
<td>Health &amp; ageing</td>
<td>131 45%</td>
<td>56%</td>
</tr>
<tr>
<td>Sustainable production</td>
<td>143 49%</td>
<td>57%</td>
</tr>
<tr>
<td>Sustainable Mobility</td>
<td>129 44%</td>
<td>35%</td>
</tr>
<tr>
<td>Other</td>
<td>13 4%</td>
<td>-</td>
</tr>
<tr>
<td>None/don’t know</td>
<td>9 3%</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>292</td>
<td>287</td>
</tr>
</tbody>
</table>

We asked the respondents to assess the potential of the different applications identified for each grand challenge. Each respondent assessed only the application for the specific Grand Challenge chosen by the respondent. We asked respondents to assess the ability of the application to solve issues related to the Grand challenge, the potential of the applications to improve European competitiveness and economic growth, the current position of Europe in each of the applications. We also asked respondents to assess the systemic complexity of the applications and the risk that user acceptance might block the realisation of applications. Systemic complexity refers to problems of reliability, or manufacturability of applications. Systemic complexity might also refer to the infrastructure needed to realise these systems.

For each question there were 3 answer categories, besides the option “do not know”. Therefore each question could receive a score of maximum 3 points. For instance, the questions concerning economic growth and the ability to solve the Grand challenge had the same answer categories: strong potential,
modest potential and no potential. If all respondent would answer that an application has a strong potential, the average score of that application would be 3.

B.1 Health and Ageing Applications

Figure 75 Ranking of the health applications

<table>
<thead>
<tr>
<th>Health and Ageing applications</th>
<th>Ability to solve GC</th>
<th>Economic growth &amp; competitiveness</th>
<th>Competitive position EU</th>
<th>Systemic complexity*</th>
<th>Risk of user Acceptance*</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miniaturised diagnostics or monitoring devices for professional use</td>
<td>2.79</td>
<td>2.72</td>
<td>2.19</td>
<td>2.22</td>
<td>2.58</td>
<td>12.50</td>
</tr>
<tr>
<td>Miniaturised self-monitoring for personal use</td>
<td>2.61</td>
<td>2.62</td>
<td>2.11</td>
<td>2.11</td>
<td>2.23</td>
<td>12.08</td>
</tr>
<tr>
<td>Devices that enable minimal invasive therapy</td>
<td>2.56</td>
<td>2.58</td>
<td>2.02</td>
<td>2.08</td>
<td>2.23</td>
<td>11.75</td>
</tr>
<tr>
<td>Assisted living facilities (smart house technologies, robots assisting in household activity, environmental assistive devices)</td>
<td>2.67</td>
<td>2.79</td>
<td>1.96</td>
<td>2.08</td>
<td>2.22</td>
<td>11.71</td>
</tr>
<tr>
<td>Other</td>
<td>3.00</td>
<td>2.67</td>
<td>2.00</td>
<td>1.71</td>
<td>1.75</td>
<td>11.13</td>
</tr>
<tr>
<td>Devices that enable the self-treatment by patients</td>
<td>2.56</td>
<td>2.62</td>
<td>2.10</td>
<td>1.76</td>
<td>1.89</td>
<td>10.94</td>
</tr>
<tr>
<td>Devices that support pharmacogenomics, gene therapy, genetic diagnosis, stem cell transplants</td>
<td>2.54</td>
<td>2.63</td>
<td>1.98</td>
<td>1.81</td>
<td>1.85</td>
<td>10.80</td>
</tr>
<tr>
<td>Replacement applications (Eg Artificial body functions and limbs)</td>
<td>2.49</td>
<td>2.47</td>
<td>1.85</td>
<td>1.89</td>
<td>2.00</td>
<td>10.70</td>
</tr>
</tbody>
</table>

Averages are based on score for each question. Minimum score is 0, maximum is 3. With systemic complexity and risk of user acceptance the rankings are reversed. A high score means low risk and low complexity.

Source: SEOR

Within the health and ageing applications the scores are highest for miniaturised devices for self-monitoring and professional diagnostics and monitoring. According to respondents, these applications have the highest potential to help address societal health and ageing issues. Devices that enable minimal invasive therapy also score high in the ability to solve health and ageing issues. Respondents were able to come up with different applications. 3 respondents ticked the option “other, namely”, but none of these filled in what the other applications would be. The category “other” scores high in the ability to solve health and ageing issues.

The devices for personal use are expected to provide most economic potential, together with assisted living facilities. Europe however has a favourable competitive position compared to other regions in devices for professional use,
according to the respondents. The devices for personal use and the devices that enable self-treatment also score high. European position is weakest in replacement applications.

The systemic complexity is lowest for professional devices for monitoring and diagnostics, but also for devices for personal use, followed by devices that enable minimal invasive therapy and assisted living facilities. Systemic complexity is highest for devices that enable self-treatment. For these applications there is also a high risk of user acceptance issues. This is less the case for monitoring and diagnostic devices for personal and professional use. There is also little risk with devices that enable minimal invasive therapy.

B.2 Climate Change Applications

For the climate change applications, on average, wind energy applications score high, mainly because of low complexity, low user acceptance and a good competitive position. In terms of the ability to solve climate change issues, Applications that neutralise emissions, transport optimising systems, and smart metering applications score high. Two respondents named other applications, namely “semi-autonomic energy communities” and “energy saving, efficiency”. 

Figure 76 Ranking of the climate applications

<table>
<thead>
<tr>
<th>Climate change applications</th>
<th>Ability to solve GC</th>
<th>Economic growth &amp; competitiveness</th>
<th>Competitive position EU</th>
<th>Systemic complexity*</th>
<th>Risk of user acceptance*</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind energy applications</td>
<td>2.54</td>
<td>2.62</td>
<td>2.64</td>
<td>2.44</td>
<td>2.40</td>
<td>12.64</td>
</tr>
<tr>
<td>Other</td>
<td>3.00</td>
<td>2.50</td>
<td>2.20</td>
<td>2.13</td>
<td>2.57</td>
<td>12.40</td>
</tr>
<tr>
<td>Applications that enable smart metering, control and sensing</td>
<td>2.72</td>
<td>2.79</td>
<td>2.25</td>
<td>2.23</td>
<td>2.33</td>
<td>12.32</td>
</tr>
<tr>
<td>(Renewable) energy transport optimising systems (e.g. smart grids)</td>
<td>2.74</td>
<td>2.75</td>
<td>2.38</td>
<td>2.04</td>
<td>2.31</td>
<td>12.18</td>
</tr>
<tr>
<td>Intelligent (household) appliances, switches, control systems and sensors</td>
<td>2.71</td>
<td>2.77</td>
<td>2.13</td>
<td>2.21</td>
<td>2.30</td>
<td>12.13</td>
</tr>
<tr>
<td>Applications that neutralize GHG / CO2 emissions (e.g. CCS)</td>
<td>2.77</td>
<td>2.72</td>
<td>2.23</td>
<td>2.15</td>
<td>2.23</td>
<td>12.09</td>
</tr>
<tr>
<td>Solar energy applications (PV and CSP)</td>
<td>2.35</td>
<td>2.40</td>
<td>2.37</td>
<td>2.43</td>
<td>2.54</td>
<td>12.09</td>
</tr>
<tr>
<td>Applications that enable improved storage of energy</td>
<td>2.38</td>
<td>2.45</td>
<td>2.16</td>
<td>2.00</td>
<td>2.43</td>
<td>11.42</td>
</tr>
<tr>
<td>Applications for other renewable energy sources (e.g. energy scavenging)</td>
<td>2.24</td>
<td>2.25</td>
<td>2.15</td>
<td>2.10</td>
<td>2.35</td>
<td>11.09</td>
</tr>
</tbody>
</table>

Averages are based on score for each question. Minimum score is 0, maximum is 3* With systemic complexity and risk of user acceptance the rankings are reversed. A high score means...
In terms of economic potential, smart metering scores highest, followed by intelligent (household) appliances and applications that neutralise emissions. Other renewable energy applications, solar energy and storage applications score lower in terms of economic potential.

Europe has a good competitive position in wind energy, compared to other regions. (Renewable) energy transport optimising systems, such as smart grids, score high on the competitive position, as well as solar energy applications. Intelligent (household) appliances score quite low on the competitive position.

Systemic complexity is lowest for solar and wind energy applications and highest for storage applications and energy transport optimising systems. Storage, wind en solar applications have the lowest user acceptance risk, but scores for each application domain are not very different.

**B.3 Sustainable production applications**

Overall, applications that enable more resource and energy efficient production processes score highest on all questions, followed by applications that enable efficient production of (more) durable goods though increased quality control. These applications score high on the ability to solve sustainable production issues and the potential for economic growth. Applications that increase supply chain management also score high in terms of the ability to solve sustainable production issues and economic growth.
Figure 77 Ranking of the sustainable production applications

<table>
<thead>
<tr>
<th>Sustainable production applications</th>
<th>Ability to solve GC</th>
<th>Economic growth &amp; competitiveness</th>
<th>Competitive position EU</th>
<th>Systemic complexity*</th>
<th>Risk of user Acceptance*</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applications that enable more resource and energy efficient production processes (e.g. combined heat power; flexible and adaptive production; system optimization; intelligent and self-adaptive machinery; zero defect manufacturing)</td>
<td>2.74</td>
<td>2.81</td>
<td>2.42</td>
<td>2.02</td>
<td>2.37</td>
<td>12.35</td>
</tr>
<tr>
<td>Applications that enable efficient production of (more) durable products using increased quality control (e.g. smart sensors and control systems)</td>
<td>2.84</td>
<td>2.73</td>
<td>2.36</td>
<td>2.04</td>
<td>2.27</td>
<td>12.24</td>
</tr>
<tr>
<td>Other</td>
<td>2.40</td>
<td>2.67</td>
<td>2.33</td>
<td>2.00</td>
<td>2.67</td>
<td>12.07</td>
</tr>
<tr>
<td>Applications that increase supply chain and logistics efficiency (e.g. RFID, wireless sensor networks, machine-to-machine communication)</td>
<td>2.68</td>
<td>2.65</td>
<td>2.16</td>
<td>2.20</td>
<td>2.33</td>
<td>12.03</td>
</tr>
<tr>
<td>Applications for resource management and conservation (e.g. environmental monitoring equipment, sensing and control devices)</td>
<td>2.53</td>
<td>2.52</td>
<td>2.32</td>
<td>2.18</td>
<td>2.35</td>
<td>11.90</td>
</tr>
<tr>
<td>Applications that enable waste treatment and recycling (e.g. smart sensor sorting; advanced density separation and recovery)</td>
<td>2.47</td>
<td>2.44</td>
<td>2.53</td>
<td>1.98</td>
<td>2.35</td>
<td>11.78</td>
</tr>
<tr>
<td>Applications that enable better workplace environments and increased safety &amp; health (e.g. new capabilities for robots and robot interfaces; measuring and sensing devices; human machine interaction)</td>
<td>2.57</td>
<td>2.47</td>
<td>2.37</td>
<td>2.02</td>
<td>2.13</td>
<td>11.57</td>
</tr>
</tbody>
</table>

Averages are based on score for each question. Minimum score is 0, maximum is 3. With systemic complexity and risk of user acceptance the rankings are reversed. A high score means low risk and low complexity.

Source: SEOR

Five respondents have answered that other applications are promising, but these do not score high in terms of the ability to solve sustainable production issues. Applications named are: “new business models, including e.g. Product service combinations”, “energy issues” and “e-school”.

According to respondents, Europe has a favourable position in waste treatment and recycling applications, but also in applications that enable more resource and energy efficient production processes and applications that enable better workplace environments. The European position is least
favourable in supply chain applications. Recycling and waste treatment applications are considered to be most complex. Least complex are applications that increase supply chain and logistics efficiency and applications for resource management and conservation (e.g. environmental monitoring equipment, sensing and control devices). The different applications scores similar on user acceptance risks, except for applications that enable better workplace environments, which scores low on user acceptance.

B.4 Sustainable mobility applications

Real-time multi-model transport information systems for individual users that enable transport optimisation and route selection applications generally score highest on average, followed by Advanced driver assistant systems. Advanced drives systems score higher on the ability to solve sustainable mobility issues, economic potential and current competitive position. In fact, it has the highest score in all the three categories (except for other in competitive position), but lower on systemic complexity and user acceptance.

Figure 78 Ranking of the sustainable mobility applications

<table>
<thead>
<tr>
<th>Sustainable mobility applications</th>
<th>Ability to solve GC</th>
<th>Economic growth &amp; competitiveness</th>
<th>Competitive position EU</th>
<th>Systemic complexity*</th>
<th>Risk of user Acceptance*</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time multi-modal transport information systems for individual users to optimise transport mode and route selection;</td>
<td>2.67</td>
<td>2.73</td>
<td>2.20</td>
<td>2.09</td>
<td>2.33</td>
<td>12.02</td>
</tr>
<tr>
<td>Advanced driver assistant systems (maritime, road, air)</td>
<td>2.72</td>
<td>2.74</td>
<td>2.48</td>
<td>1.95</td>
<td>2.02</td>
<td>11.91</td>
</tr>
<tr>
<td>Other</td>
<td>2.00</td>
<td>2.33</td>
<td>2.83</td>
<td>2.25</td>
<td>2.40</td>
<td>11.82</td>
</tr>
<tr>
<td>Traffic management and control systems (electronic signs; signals; surveillance and monitoring)</td>
<td>2.46</td>
<td>2.59</td>
<td>2.31</td>
<td>2.18</td>
<td>2.25</td>
<td>11.79</td>
</tr>
<tr>
<td>Applications that enable emission and (fossil) energy reductions in vehicles and ships (hybrid and/or electric; battery improvements)</td>
<td>2.59</td>
<td>2.69</td>
<td>2.17</td>
<td>1.98</td>
<td>2.27</td>
<td>11.68</td>
</tr>
<tr>
<td>Automated road-user charging to optimise flow and reduce emissions (based on distance travelled, time of day, type or weight of vehicle, level of pollution )</td>
<td>2.50</td>
<td>2.48</td>
<td>2.34</td>
<td>1.98</td>
<td>1.74</td>
<td>11.03</td>
</tr>
<tr>
<td>Logistics solutions to optimize the inter-change between long- and short distance travel</td>
<td>2.23</td>
<td>2.30</td>
<td>2.18</td>
<td>1.95</td>
<td>2.31</td>
<td>10.96</td>
</tr>
</tbody>
</table>

Averages are based on score for each question. Minimum score is 0, maximum is 3. With systemic complexity and risk of user acceptance the rankings are reversed. A high score means
Three respondents name other applications. One is road surface monitoring and the other is “distributed IT systems of geo-information, and customer sensitive delivery”

Applications that enable emission and (fossil) energy reductions in vehicles and ships (hybrid and/or electric; battery improvements) score quite high on the ability to solve sustainable mobility issues and economic potential, but rather low on the current competitive position and systemic complexity and user acceptance. Automated road-user charging applications scores quite high on the ability to solve the Grand Challenge, economic potential and competitive position, but low on systemic complexity and especially low on the risks of user acceptance.

B.5 Weighing the criteria and ranking the applications

In this section we discuss the criteria for selecting the most promising applications out of the long list of applications. One of the main issues is how to weight the results. For each of the criteria used in this survey different applications emerge as most promising. Since public acceptance risks are not seen as very important, we did not include this aspect in our final ranking. This has another advantage. As we are looking for new and especially challenging applications, including the public acceptance risk would give “safe” applications a higher ranking. In most cases, however, these applications fall short in terms of economic potential and the ability to solve Grand challenges. By excluding acceptance risk the focus remains on highly promising applications.

We are also very much interested in applications that have a high potential for research. For this reason we include a revision of the systemic complexity variable in the rankings. Systemic complexity refers to reliability and manufacturability problems in developing products for each specific application. In case many problems are expected this means that more research is needed. The survey suggests that most challenges are present in the development phase of applications and especially for applied research. If hardly any problems exist, there are probably few research challenges, but if many problems exist, perhaps the applications are not very promising. We therefore changed the scores of each answer (3 points if systems complexity is average, 2 if systemic complexity is high and 1 if systemic complexity is low), to increase the ranking of applications that have an average, or high systemic complexity. As this measure is not an explicit measure of research challenges we decreased the weight of this variable to 50%. Another reason to decrease the weight is that we noticed that systemic complexity has a strong impact on the results and by including the full weight, more applications were selected that score low on the other three criteria. Decreasing the weight ensures that the focus lies on highly promising applications.
The rankings are based on the average scores of four criteria. Applications score high, if the contribution to solving issues of a specific grand Challenge is high, if there is high potential for economic growth and competitiveness, if the competitive position of Europe in this application domain is strong and if systemic complexity is average or high.

No weights are applied for each Grand challenge. The results can be weighted by the importance attached to the each Grand Challenges. This however could create a bias, as these results are mostly based on the sampling method used. The results would then reflect the sample. Moreover, the respondents are quite evenly divided over the Grand challenges. Only for sustainable mobility the number of respondents is lower. Since averages are taken, this does not influence the results. As we do not expect that people who are active in a certain Grand Challenge are more or less inclined to answer positive or negative than in other Grand Challenges, taking averages is not expected to lead to biased results.

There is a difference in the answers between those who do not use, or apply IMS in their products, research or services and those who do apply IMS. The differences are small however. On average scores are lower, but also the variance in the answers is higher for respondents that use IMS. Since we are more inclined to value the answers given by those who do use IMS, as these are expected to be more knowledgeable concerning the potential impact, we base the final selection on the average scores of the answers given by respondents who apply IMS. This gives the following ranking:

Figure 79 Rankings

<table>
<thead>
<tr>
<th>Grand Challenge</th>
<th>Application</th>
<th>Ability to solve</th>
<th>Economic potential</th>
<th>Competitive position</th>
<th>Systemic complexity</th>
<th>Average score</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>Applications that enable more resource and energy efficient production processes (e.g. combined heat power; flexible and adaptive production; system optimization; intelligent and self-adaptive machinery; zero defect manufacturing)</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>SM</td>
<td>Advanced driver assistant systems (maritime, road, air)</td>
<td>14</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>SP</td>
<td>Applications that enable efficient production of (more) durable products using increased quality control (e.g. smart sensors and control systems)</td>
<td>2</td>
<td>6</td>
<td>13</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>HA</td>
<td>Miniaturised self-monitoring for personal use</td>
<td>3</td>
<td>3</td>
<td>17</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>SM</td>
<td>Applications that enable emission and (fossil) energy reductions in vehicles and ships (hybrid and/or electric; battery improvements)</td>
<td>13</td>
<td>2</td>
<td>20</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>CC</td>
<td>Applications that enable smart metering, control and sensing</td>
<td>6</td>
<td>4</td>
<td>16</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>HA</td>
<td>Miniaturised diagnostics or monitoring devices for professional use</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>21</td>
<td>7</td>
</tr>
</tbody>
</table>
The two sustainable production applications score high in the ability to solve issues related to the Grand Challenges and economic potential. This is very similar for respondents who do not apply IMS. Scores are lower for the competitive position and systemic complexity.

Health and aging applications that score high overall are miniaturised diagnostic and monitoring devices for personal and professional use. Both have a high rating in terms of the ability to solve issues related to the Grand challenge and economic potential, but according to respondents the position of Europe in these devices is not very strong. This is also very similar between respondents who do not use IMS and do apply IMS.

Smart metering applications and (Renewable) energy transport optimising systems score high in climate change applications. Smart metering scores high on the ability to solve and economic potential, but lower on competitive position. (Renewable) energy transport optimising systems do not score very high overall for all four criteria, however, due to the many combinations possible these applications are still in the top 10. If we, however, take the whole sample into account, (renewable) energy transport optimising systems are rated higher. There is more variability between respondents who use IMS and those who do not use IMS for climate change applications. Probably the main reason is that climate change respondents have the lowest share of respondent active in IMS. Respondents that use IMS rate smart metering higher, than those who do not use IMS.

There are four applications for sustainable mobility in the ranking. Advanced driver assistant systems and applications that enable emission and (fossil) energy reductions in vehicles are seen as most promising. Advanced driver assistant systems do not score very high in the ability to solve and economic potential, but does score high on competitive position. This is reversed for applications that enable emission and (fossil) energy reductions in vehicles. Again differences between the two groups are not very different for these two applications.
### Figure 80 Respondents by organisation

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Respondents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Manufacturing) Company</td>
<td>62</td>
<td>19.7</td>
</tr>
<tr>
<td>University</td>
<td>39</td>
<td>12.4</td>
</tr>
<tr>
<td>Public research institute or not-for-profit</td>
<td>77</td>
<td>24.5</td>
</tr>
<tr>
<td>research institute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private research institute</td>
<td>36</td>
<td>11.5</td>
</tr>
<tr>
<td>Engineering &amp; Consultancy</td>
<td>54</td>
<td>17.2</td>
</tr>
<tr>
<td>Other, namely:</td>
<td>46</td>
<td>14.6</td>
</tr>
<tr>
<td>Total</td>
<td>314</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: SEOR

### Figure 81 Respondents by function for (manufacturing) companies

<table>
<thead>
<tr>
<th>Function</th>
<th>Respondents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>General management</td>
<td>14</td>
<td>22.6</td>
</tr>
<tr>
<td>Engineering and design</td>
<td>3</td>
<td>4.8</td>
</tr>
<tr>
<td>R&amp;D (management)</td>
<td>32</td>
<td>51.6</td>
</tr>
<tr>
<td>Production management</td>
<td>2</td>
<td>3.2</td>
</tr>
<tr>
<td>Marketing and business development</td>
<td>8</td>
<td>12.9</td>
</tr>
<tr>
<td>Other, namely:</td>
<td>3</td>
<td>4.8</td>
</tr>
<tr>
<td>Total</td>
<td>62</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: SEOR

### Figure 82 Respondents by function

<table>
<thead>
<tr>
<th>Function</th>
<th>Respondents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>(General) Management</td>
<td>65</td>
<td>26.0</td>
</tr>
<tr>
<td>(Assistant) Professor</td>
<td>21</td>
<td>8.4</td>
</tr>
<tr>
<td>Department Leader</td>
<td>50</td>
<td>20.0</td>
</tr>
<tr>
<td>Researcher</td>
<td>50</td>
<td>20.0</td>
</tr>
<tr>
<td>Consultant</td>
<td>33</td>
<td>13.2</td>
</tr>
<tr>
<td>Marketing/PR/Communication</td>
<td>3</td>
<td>1.2</td>
</tr>
<tr>
<td>Other, namely:</td>
<td>28</td>
<td>11.2</td>
</tr>
<tr>
<td>Total</td>
<td>250</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: SEOR

### Figure 83 Respondents by country

<table>
<thead>
<tr>
<th>Country</th>
<th>Respondents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>10</td>
<td>3.2</td>
</tr>
<tr>
<td>Belgium</td>
<td>46</td>
<td>14.7</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Cyprus</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>Country</td>
<td>Value</td>
<td>Percentage</td>
</tr>
<tr>
<td>------------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Denmark</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Estonia</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>Finland</td>
<td>13</td>
<td>4.2</td>
</tr>
<tr>
<td>France</td>
<td>16</td>
<td>5.1</td>
</tr>
<tr>
<td>Germany</td>
<td>32</td>
<td>10.3</td>
</tr>
<tr>
<td>Greece</td>
<td>10</td>
<td>3.2</td>
</tr>
<tr>
<td>Hungary</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Ireland</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Italy</td>
<td>36</td>
<td>11.5</td>
</tr>
<tr>
<td>Latvia</td>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td>Lithuania</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Netherlands</td>
<td>18</td>
<td>5.8</td>
</tr>
<tr>
<td>Norway</td>
<td>5</td>
<td>1.6</td>
</tr>
<tr>
<td>Poland</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Portugal</td>
<td>10</td>
<td>3.2</td>
</tr>
<tr>
<td>Romania</td>
<td>4</td>
<td>1.3</td>
</tr>
<tr>
<td>Slovakia</td>
<td>5</td>
<td>1.6</td>
</tr>
<tr>
<td>Spain</td>
<td>39</td>
<td>12.5</td>
</tr>
<tr>
<td>Sweden</td>
<td>15</td>
<td>4.8</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>20</td>
<td>6.4</td>
</tr>
<tr>
<td>Other, namely</td>
<td>5</td>
<td>1.6</td>
</tr>
<tr>
<td>Total</td>
<td>312</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: SEOR
Appendix C  Healthy ageing

The world’s ageing population will lead to a raised demand for healthcare while the working population decreases. It will most likely push up healthcare spending, however, if people remain healthy as they live longer, the rise in healthcare spending due to ageing could be halved. Therefore, **The main challenge is to support healthy ageing throughout the lifespan, aiming to prevent health problems and disabilities from an early age, and tackling inequities in health linked to social, economic and environmental factors.**

C.1  Trends and Drivers

In this section, trends and drivers for the grand societal challenge are explored and assessed. For this purpose we use the heuristics of STEEP-analysis\(^\text{72}\), which systematically analysis societal, ecological, technological, economical and political aspects.

C.1.1  Societal

- **Aging populations overwhelm the system.** Aging population with lead to increases in the number of people suffering from chronic, expensive-to-treat diseases and disabilities, straining health care systems.
  
  - The average number of children per woman, which stands at 1.5 children in the EU whereas the population replacement level is 2.1. The rate projected by the EU for 2030 is 1.6;
  
  - **Life expectancy** (which rose by eight years between 1960 and 2006) could continue to increase by a further five years between 2006 and 2050 and would thus result in a larger proportion of people surviving to the ages of 80 and 90 – an age when their health situation can often be delicate. The United Nations (2007) predicts that by 2050 the number of people aged 60 and older in developed countries will have increased from 21% today to 32%, and in the less-developed countries from 8% today to 20%.

\(^\text{72}\) Also known as STEEPV, or many other slightly varying acronyms.
- Longer life does not necessarily lead to more years of suffering for the individual. On the contrary, “compression of morbidity” will lead to an increase in Healthy Life Years.

- Immigration (1.8 million immigrants into the EU in 2004, 40 million in 2050 according to Eurostat’s projections) could offset the effects of low fertility and extended life expectancy. However, as immigrants adapt to their new environments with regard to life expectancy and birth rates, this effect is limited and not sustained over generations.

Figure 84 Global age pyramids

WEF, 2008 (The Future of Pensions and Healthcare in a Rapidly Ageing World Scenarios to 2030)
Figure 85 Age pyramids for EU 25


- **Falling working-age population.** The working-age population (15 to 64) in EU-25 will fall by 48 million between 2006 and 2050 and the dependency ratio is set to double, reaching 51% by 2050. The World Bank (2007) expects the labour force in high-income countries to peak in 2010 and then begin to shrink significantly. There will also be a considerable slowdown in labour force growth in East Asia, including China.

Figure 86 Declining employment and working age population

Source: DG ECFIN

• **Changing life styles and life style related diseases (obesity, diabetes, coronary heart disease) will be a major future health challenge.** A British foresight report ‘Tackling obesities: Future Choices’ predicts that by 2050 half of the UK population might be obese, and that the costs for the national health system attributable to overweight are projected to double to 10 billion pound per year by 2050. Urban life style and increase of single households and changing family patterns will lead to an increased demand for formal care. There will still be neurodegenerative diseases around, as well as cancer. Not all country epidemiological studies however back up the worrying data about obesity as presented above (German data for instance does not back up the conclusions drawn by the UK foresight report).

• **Patients increasingly demand better information** about their condition, treatment options and performance of clinical teams. Self-monitoring and self-ownership is increasingly important for patients.

• **Global pandemics.** Urban sprawl, population growth, global travel, and rudimentary delivery systems in poor countries ensure that global pandemics will remain a serious threat.

C.1.2 Ecological

• **Environmental challenges.** The effects of poor water and air quality, pathogens in food supply and urban sprawl and congestion will cause dramatic health care challenges for decades to come.

• **Changing climates** may cause diseases to spread to regions they were not originally natural to (return of Malaria to Europe, West-Nile-Virus example in the US and southern Europe)

C.1.3 Technological

• **The advancement of genetics allows for genetic screening and the prevention of diseases, and personalised medicine.** The cost of genomics decrease quickly, and the market for genome decoding will explode. This will lead to a greater understanding of disease and the development of new therapies but will raise complex privacy and cost-benefit issues. Data interpretation is a huge challenge here, as well as ethical consideration. Moreover, no genuine gene therapy has been successful up to date.

• **Dominant technologies in healthcare will develop around three clusters:** Genetic Technologies (GENTEC), Medical technologies (MEDTEC) and Information and Communication Technologies (ICTEC)
with applications such as pharmacogenomics, gene therapy, genetic diagnosis, stem cells, telemedicine and telecare, minimal invasive surgery and new imaging techniques, lab-on-a-chip, neuro implants, neuro chips, etc. Regenerative medicine, tissue engineering, and the development of biomaterials appear particularly promising.

- **Biotechnology and nanotechnology getting increasingly interrelated.** This is particularly promising for future medicine in e.g. the area of cancer (nanotechnology based imaging procedures and targeted drug delivery), genetic interventions (gene therapy) and tissue engineering (substitution for organ transplants and for curing neuro-degenerative diseases.). Since nano-particles can cross the brain-blood barrier, nanotechnology is specifically promising for brain-related diseases. However promising, nanotechnology itself may pose serious and hard to control health threats. German (and EU) authorities have concluded, that some common nanomaterials may be cancerogenous (http://www.bfr.bund.de/cm/343/beurteilung_eines_moeglichen_krebsrisikos_von_nanomaterialien_und_von_ausprodukten_freigesetzten_nanopartikeln.pdf) and that monitoring is necessary. This debate is just evolving, but it may pose a serious to the further use and development of nanotechnologies.

- **Increased area of 'human enhancement technologies' (HET).** Technologies that not only treat diseases but improve the capabilities of healthy individuals. This causes ethical challenges and financing and equity challenges.

- **Technological developments will be integrated in everyday devices to assist in and outside the home.** Examples are functional clothing, with particular regard for older persons with chronic diseases; the development of fall safe floors; the design of intelligent textiles and smart clothing featuring new properties and incorporating IT and communications solutions directly into the garment; assisted living facilities; drugs and food delivery services; barrier free access to public transport, etc.

C.1.4 Economic

- **Rising costs.** Costs for healthcare will continue to rise and will have a widespread impact on health care spending, design of national systems and delivery. However, technological innovation also leads to more efficient and less costly treatments plus it allows for a gain of healthy or disability free life years – people that can be productive longer and contribute to the economy. For instance, the total costs caused by Alzheimer’s disease are estimated in the range from 2,470 Euro to 32,000
euro per patient per year. The costs for age related diseases are likely to rise to potentially increasing number of cases.

- **Payers’ influence over treatment decisions.** Rising costs around the world will cause the power to decide how to treat patients to shift from health-care professionals to payers, who will assess the added ‘quality-adjusted life years’ that a potential treatment offers. Some major pharmaceutical companies are already responding by changing their R&D strategies.

- **There might be pressure on public pensions and healthcare systems** due to rapid population ageing, cost-increasing medical technologies and higher incidences of chronic diseases. China, for example, will be confronted with a significant increase in old-age social security expenditures in the next few decades. It is however problematic to make general remarks about social security system that are valid across countries due to extremely different operational models. Healthcare systems and pension systems work in a completely different way.

There is no evidence however to date (though many claims) that asset based systems are more stable than pay-as-you-go systems. The asset based pension system in the US basically collapsed in many aspects during economic crisis while Europe’s PAyG systems coped relatively well. “Private” asset based health insurance in Germany has to fight much higher increases in cost and premiums than the “public” PAyG system over the last couple of years.

Figure 87  Dependency ratio highest in Europe

![Dependency ratio highest in Europe](image_url)

WEF, 2008 (The Future of Pensions and Healthcare in a Rapidly Ageing World Scenarios to 2030)
• **Future health spending**

With regard to technologies for the ageing population, the match between technologies on offer and actual user needs is far from optimal. Lack of acceptance, lack of usability or even of usefulness, are often diagnosed as reasons for limited technology diffusion in this area. They are also indicators of the mismatch between technologies supplied and technologies needed. User needs are ill understood, existing mechanisms for their articulation and integration into the technology development process are insufficiently mapped, and new strategies for more user involvement have barely been elaborated. Medical research priorities in most high-resource countries are based primarily on scientific and technological preferences, with little explicit regard for public health needs (WHO 2010).

Global expenditure on health research has more than quadrupled to over US$ 125 billion in 2003 and US$ 160.3 billion in 2005 (Global forum for health research); Research pertinent to the needs of developing countries is “grossly under-resourced in many areas”, according to the Global Forum on Health Research. This discrepancy in health research funding is captured in the so-called “10/90 gap”, a term coined in 1990 by the Global Forum on Health Research to highlight the fact that only 10% of global health research expenditure is devoted to conditions that together account for 90% of the global disease burden (WHO 2010).

For health and aging, the costs of aging matter, but perhaps more importantly is the human dimension, or society’s ability to integrate elderly people, to prevent social isolation. Health spending represents 9% of OECD economies (2008). It exceeds 10% in seven OECD countries – the United States, France, Switzerland, Austria, Germany, Canada and Belgium. Factors exerting upward pressure on health spending (technological change, population expectations, increased incomes and, to a varied extent across countries, population ageing) will continue to drive health spending higher in the future. According to OECD projections, public health spending could increase by between 50% and 90% by 2050, depending on the assumptions made.

In-patient care (i.e. predominantly provided in hospitals) and ambulatory care together account for around 60% of health spending. With in-patient care highly labour intensive and, therefore, expensive, high income countries with developed health systems have sought to reduce the share of spending in hospitals by shifting to more day surgery, out-patient or home-based care. Expenditure on long-term care, either in institutions or in a home-based setting now accounts for more than 12% of total health spending on average, and considerably more in countries where there is already a sizeable elderly population. (OECD 2010).
The contribution of ageing to past health spending growth appears modest. It ranges from 6.5% to 9% of the increase in total health care spending over the period 1960 to 1990 but the results depend on estimation strategy, type of data, country and period considered. Income changes are credited with having a higher contribution to health spending growth in all studies, ranging from 28% to 58% (OECD 2009).

The contribution of technological progress is often measured as the residual when respective contributions of other factors have been estimated. Initial estimates by Newhouse (1992) attributed 50 to 75% of health expenditure growth to changes in technology. More recent estimates on US data over 1960-2007 range from 27.4 to 48.3% according to alternative working hypotheses (Smith et al., 2009). Dormont et al. (2006), working on microdata, showed that “changes in medical practice” – for a given level of morbidity – explained about a quarter of health spending growth in France between 1992 and 2000 (OECD 2009).
• **Medical tourism.** The allure of good care at much lower prices will cause increasing numbers of people to go abroad for cheaper treatment.

• **The so-called ‘silver market’ provides new opportunities** since the purchasing power of this market is strong. In Germany e.g. it is estimated that the purchasing power of the 60+ generation amounts to some EUR 316 billion, contributing to nearly one third of the total private consumption. According to a German study, this will increase to 41% in 2050.

  – **Prevention is the next big business opportunity.** More dollars will be spent on vaccines and other means of preventing or reducing the incidence and severity of serious diseases (e.g. cancers) and chronic disorders (e.g. obesity related illnesses such as diabetes). It remains to be seen whether consumers will cooperate. Smoking is only slowly diminishing and a disappointing number of people are getting colonoscopies. In the U.S chronic disease, much of which is preventable, accounts for 75% of health care spending.

  – **Innovation and demand increase in emerging economies.** Spending on health care in Emerging Economies will continue to rise in line with their economic growth, and they will become big markets for health care companies. Serving them will require innovations in technologies and delivery and business models. Demand for vaccines...
and treatments for traditionally ‘western’ diseases will increase in these countries.

C.1.5 Political

- **Patients more and more become ‘consumer patients’,** and expect the best quality healthcare at an affordable price. This raises challenges of providing equal and affordable access to modern health services for all. The civil society will become a ‘serious player’ influencing the political decision-making process.

- **Growing role of philanthropy.** Foundations and other NGOs will play a leading role in funding research to develop drugs and delivery systems for preventing and treating diseases that mainly plague poor countries (e.g. malaria and TB)

- **Possibly increasing public-private or public-public partnerships and cooperation models** in the EU such as the Innovative Medicines Initiative (although this won’t be replicated in the future); the European Innovation Partnership on Active and Healthy Ageing; and Joint Programming on Alzheimer’s disease.

C.2 Problem analysis

Low birth rates, increasing longevity lead to a growth of people aged 65+ in the EU by 70% in 2050. The 80+ group will grow by 170%. This will lead to a raised demand for healthcare while decreasing the working population. It could push up healthcare spending by 1 to 2% of GDP in MS by 2050. On average this would amount to about 25% increase in healthcare spending as a share of GDP. However, if people remain healthy as they live longer, the rise in healthcare spending due to ageing would be halved.

So, **the main challenge is to support healthy ageing throughout the lifespan, aiming to prevent health problems and disabilities from an early age, and tackling inequities in health linked to social, economic and environmental factors.** Better-adapted healthcare services and prevention of chronic diseases could reduce public spending. Moreover, new technologies can potentially contribute to future sustainability by improving healthcare and health systems. Examples can be found in genetic technologies, medical technologies and information and communication technologies.

The EU will need to cope with:

- **Demographic change**
• Balancing equity and cost efficiency
• Cost-benefit analysis with regard to emerging medicine and preventative measures
• Prevention and rehabilitation
• New concepts for the labour market and pensions
• New health systems and technologies, and the hospital of the future
• Healthy in the home concepts

C.3 Sources

<table>
<thead>
<tr>
<th>Title</th>
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Appendix D Climate Change

Human activities influence our environment. Our activities impact the climate by the mechanism of the greenhouse effect, i.e. the rise in temperature that the Earth experiences because certain gases in the atmosphere trap energy from the sun. Additional emission of those gases (e.g. CO$_2$, N$_2$O, CH$_4$) due to human activity leads to amplification of the greenhouse effect. The most apparent effect of the amplification of the greenhouse effect is an increase in temperature. Since the first Industrial Revolution the average temperature has raised dramatically – i.e. the so-called hockey stick curve – hand-in-hand with the increase of emissions due to industrialisation. The concentration of atmospheric CO$_2$ has increased from about 280 parts per million (ppm) in pre-industrial times to more than 387 ppm in 2008$^{73}$. As a result, the temperature in our climate increased dramatically and is expected to continue to increase. The average global air temperature by 2009 had risen by 0.7-0.8 °C above the preindustrial level. Current projections suggest global mean temperatures could rise by as much as 1.8-4.0 °C over the course of this century if global action to limit GHG emissions proves unsuccessful$^{74}$.

Several societal problems are rooted in this change of our climate, such as:

- More extreme weather conditions, causing drought and flooding; thus influencing:
  - Food supplies;
  - Drinking water supplies;
- Rising sea level, endangering coastal areas with flooding;
- Health issues related to heat waves (related to GC healthy ageing);
- Desertification.

A number of trends and drivers can be influential on the effects of the greenhouse effect; and which offer possible solutions for Climate Change. Please note that sustainable transport is another Grand Challenge, and therefore out of scope of this chapter.

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$^{73}$ Richardson et al., 2009
$^{74}$ IPCC, 2007
D.1  Trends and Drivers

In this section, trends and drivers for the grand societal challenge are explored and assessed. For this purpose we use the heuristics of STEEP-analysis, which systematically analyse societal, ecological, technological, economical and political aspects.

D.1.1  Societal

7. Increased activity in society means higher energy use. Unfortunately, our society is based on a low-cost energy system. We primarily burn fossil fuels to power our society. As a result, almost 80% of the EU's emissions of greenhouse gas are energy-related. Energy supply is one of the largest contributors to the emission of greenhouse gases. Especially the emission of carbon dioxide is generally observed to contribute to a change in atmosphere, leading to Climate Change. Society's energy supply is based on fossil fuels. Society's uptake of fossil fuels leads to emissions of Greenhouse Gases (GHG). This trend gave rise to a set of technologies to prevent GHG emissions, which will be dealt with in section D.1.2.

8. The energy demand in the world will increase dramatically, due to changes in demographics and economic standards. Climate change is a global issue that does not stop at borders. Therefore, the EU is also confronted with developments in the world. Changes in demographics include: (i) growing world population and continuing urbanisation (ii) growing wealth. Increasing wealth and an urban population will lead to even growing GHG emissions.

vi) Growth of world population and urbanisation of world population will lead to increased emissions of GHG (see Figure 90);

vii) Both the world economy and the EU economy are expected to grow. Economic growth is still coupled to energy intensity especially in extra-EU countries; although the link is weakening in EU countries (see Figure 91)

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75 Energy 2020
76 Vision 2050
9. Specifically for the EU:

viii) Future assessments of the EU population will be rather stable (500 million citizens in EU27); thus following the trend of the. Due to our social structure (smaller families, less people per household), the number of households is increasing (source: Environmental statistics and accounts in Europe). Increase of the number of households significantly drives the emissions of GHG through construction activities and less efficient use of energy, as a smaller number of people share the same hardware.
D.1.2 Technological

Energy technology is developing into ways that avoid GHG-emissions. Many alternatives are developed that aim at decoupling economic and demographic growth from fossil energy use. There are grossly three technological pathways, which require:

10. Indigenous energy sources;

Several renewable energy technologies are being developed to cope with Climate Change – the energy mix is increasingly depending on renewable energy sources (RES).

Figure 92 Increasing importance of renewable sources

![Graph showing increasing importance of renewable sources](image)

**BP Energy Outlook 2011**

Figure 93 Projections of growth of renewable supply for electricity until 2020.

![Graph showing projections of growth of renewable supply for electricity until 2020](image)

**EC, 2007. Renewable Energy Road Map Renewable energies in the 21st century**

Furthermore, there still is large potential for RES, as several of these technologies are in early stages of implementation. Currently, the largest RES
sources are wind energy and solid biomass (see Figure 93). All types of RES are expected to grow. Fast growth is expected for biomass and biogas, wind energy and photovoltaics.

As RES become cheaper as the installed capacity increases. A recent baseline for a large energy roadmap estimated that the learning rate is expected to be highest for solar PV. Cost for renewable energy sources are crucial for successful implementation of RES. The estimated applying learning rates, i.e. the cost reduction after doubling of the installed capacity; below we specify the largest renewable energy sources and their learning rates:

- **Wind power** has grown steadily since the 1980s, constituting about 5% of today’s European power production. Scaling up could lead to increased load factors of about 25-30%. The learning rate is estimated to be about 5%; but with the current installed capacity a doubling of the capacity will cost quite an effort.

- **Solar PV**’s load power is estimated at 17% for Southern Europe and about 10% for Northern Europe. The learning rate is estimated by the industry on 15%.

- **Biomass** power plants. As biomass power plants use biological matter as fuel, they are assumed to be carbon neutral. Dedicated power plants are assumed to generate up to 250MW; a yearly decrease of cost of 1% per year seems to be reasonable.

- **Concentrated solar power** plants use lenses and mirrors to reflect sunlight on a high-power solar cell. This technology holds primarily promise for southern European countries. The potential is estimated to be 300TWh per year – the learning rate is unclear.

- **Geothermal power** relies on heat from the earth’s core – the potential is limited to about 2% of the European demand in 2010, due to limited suitable locations. Conventional geothermal is a mature technology with a low learning rate around 1%.

- **Hydropower** is the largest installed RES. Most of the commercially and sociably acceptable sites have been commercialised so a limited growth is to be assumed (IEA EWO 2009 projection).

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77 Based on the baseline study of the Energy Roadmap 2050

78 Yet acknowledging that the current share of pv in the total energy mix is very low.
• *Tidal power* no specific information is available on this technology; although it does hold potential for the EU in several areas – it is also part of the EU Framework Programme.

Next to RES, nuclear power does not emit GHG, but is not likely to grow significantly.

11. **Cleaning of fossil sources**;

The so-called end-of-pipe-solutions are seen as a temporary mean to get rid of emissions; until indigenous sources are capable of the fulfilling the energy demand. Cleaner use of fossil fuels is relatively highly developed, and is now being integrated in the EU system. In a recent energy roadmap, CCS is seen as a very promising emerging technology to clean fossil fuels. Several demonstration projects are currently under development in a number of Member States; Norway leading the pack. **Carbon Capture and Storage (CCS) is observed to be a good mean to drastically bring down emissions of GHG**, as a temporary solution until RES are able to take over a large share in the energy supply mix.

12. **Increased efficiency and integration of solutions**

Increased efficiency of energy use is identified to be just as important as a cleaner supply of energy (see the political section). Many of the saving strategies are relatively low tech (isolation) or behavioural and are not too relevant for this matter.

Identified as an important issue are smart grids. Smart grids have a three-way importance:

- Smart grids are necessary to manage the instable and fluctuating energy supply of RES;
- Smart grids allow more efficient transport of energy;
- Smart grids allow for better consuming behaviour by the end-consumer.

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79 Ibid.
80 Ibid.
D.1.3 Economic

ix) **In the EU GDP per capita will rise, as will the purchasing power.** The EU population will be rather stable (500 million citizens of EU27), but the GDP is likely to increase with a factor 2 from about €10 trillion to €22 trillion in real terms (IEA projections). This implies that the GDP per capita doubles, which will increase the purchasing power of EU citizens.

x) **The energy intensity will reduce with 1-1.5% per year.** Energy intensity is the amount of energy that is required per Euro added value. Especially industry will remain energy intensive, but they are projected to decrease with 1-1.5% per year. This leads to a 50% decrease in about 40 years time.

**Renewable energy technologies start to be economically viable when compared to traditional sources** due to:

- lower cost per energy unit of renewable sources;
- higher costs of fossil sources (primarily oil);

But are yet still depending on public investments to level the lower cost of fossil fuels.

D.1.4 Political

- **Policies at all levels of governance exist, which are aimed at Climate Change mitigation.**
  - World level: UNFCC has the two-degree target
  - European Council: reduce GHG by 20% by 2020 by 20% increase of renewables, 20% improvement of energy efficiency.
  - Member States all accept the policy goal as set at EU level; but the ways to get there differ largely: different RES are stimulated in different ways, thus making the EU system rather fragmented and less robust for EU industry.

This makes the total set of policies rather

The recent perceived failure of the climate conference in Copenhagen and growth of scepticism towards climate change by the vox populi are important uncertainties regarding this matter.

- **Apart from Climate Change mitigation a number of policy drivers exist for a shift towards renewable resources:**
- Security of supply: governments do not want to be dependent on politically unstable or unreliable states
- Depletion of resources: the prediction that our fossil sources will be depleted in 40 years, now nearly holds for 40 years. Fossil fuel sources have never been so large as they are now (BP, 2010). Main cause for this are innovations in the discovery and recovery technologies for oil and gas: more sources are discovered, and more fossil fuels can be distracted from one source.

- **Internal energy markets are fragmented and hampered by national regulations; thus leading to barriers in fair and open competition.**

D.2 Problem Analysis

D.2.1 Summing up the trends and drivers

Climate Change concerns enormous systems (i.e. climate), which are largely beyond human control. Most important interactions between society and the climate are in the global emissions of greenhouse gases; although deforestation, land-use change and agriculture also provide significant but smaller contributions. Main challenge of climate change is to reduce the emission of greenhouse gas. Climate change is largely related to use of energy: 80% of the EU emissions are energy-related. Figure 94 shows the largest causes for emissions at world level. Other large contributors are building (cement production) and agriculture, both in the Western as in the developing world.

Figure 94 Greenhouse gas emissions

In the EU27, population is relatively stable, and energy intensity is decreasing due to increased efficiency in industry, emergence of RES, and cleaner fossil sources, but an increasing GDP and associated rise in consumption will offset this. As a consequence of growing consumption, power demand might increase with 40% over 45 years (annual growth <1%). Improved power intensity will offset increased energy usage by the increase in GDP, roughly to 40% of its 2010 value (see figure below).

Figure 95  Projected final energy consumption in the EU

At a global level, increasing urbanisation and population, as well as the increase in GDP will certainly drive up the emissions of GHG, and might even rise with more than a quarter in the next 20 years (see Figure 6). Given the increase in population, economic growth an increase in GHG is to be expected. Non-OECD countries will account for 97% of the projected increase. China, India, and the Middle East will take a three quarter share in this increase. As climate change is a global problem, this will influence the EU; although this issue is largely beyond the policy influence of the EU

Figure 96  Greenhouse gas emissions
xii) Renewable Energy Sources are projected to be of growing significance in dealing with GHG emissions. Especially wind and biomass power are expected to be important sources. Photovoltaic energy’s price is likely to drop the fastest, as it is projected to be the technology with the highest learning rate.

xii) Smart grids and smart metering are promising means for increased efficiency at network level.

D.3 Sources

D.3.1 Visionary documents

<table>
<thead>
<tr>
<th>Title</th>
<th>Year</th>
<th>Author/organisation</th>
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<tr>
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<tr>
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<td>International Council for Science (ICSU)</td>
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<tr>
<td>Towards a Green Economy</td>
<td>2011</td>
<td>UNEP</td>
</tr>
<tr>
<td>The Eco-Innovation Challenge: Pathways to a resource-efficient Europe</td>
<td>2010</td>
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</table>
### Publications related to the application of IMS:


Appendix E Sustainable Production

...the major cause of the continued deterioration of the global environment is the unsustainable pattern of consumption and production... UN Agenda 21, Chapter 4 (1992)

Production of goods brings along consumption of energy, resources and often outputs that pollute the environment. Because of the increasing productivity of our society, we face a challenge to be able to increase energy and resource efficiency of production, while minimising the environmentally hazardous output. This is due to the fact that environmental impacts occur at every stage of production chains. Energy and resources are used, while emissions are released into water, air, and soil.

Most prominent environmental problems are connected to use of materials and energy. Not only this influences our climate, but also leads to degradation of ecosystems and the use of ecosystems. Unsustainable production thus brings along a number of societal problems, such as shrinking water reserves and forests, depletion of scarce materials, extinction of species and erosion of fertile land. Extraction of large amounts of materials furthermore impacts land cover and biodiversity.

For sustainable production, increased resource efficiency is thus key. In order to deal with sustainable production, at European level the main solutions are sought in eco-innovation.

E.1 Trends and drivers

E.1.1 Societal

- Societies have always been based on natural resources. Since the industrial revolution, this extraction is geared towards unprecedented levels, most notably since the Second World War. Only in the period from 1980 to 2007, worldwide resource extraction and resource use increased by 62%, with extraction of resources by the global economy growing from 40 to 60 billion tonnes (SERI 2010). Model calculations of a business-as-usual scenario show that the global annual material use will increase to 100 billion tonnes by 2030 (Lutz and Giljum, 2009).

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85 The challenge of a sustainable energy supply is already dealt with in the document on the Grand Challenge climate change.
Increasing consumption will put increased pressure on sustainable production – main driver at world level are increased consumption caused by economic and demographic changes. Figure 97 summarises the expected problems by SERI if no action is taken until 2060 – below the demographic and economical aspects are specified.

Figure 97 Summary of sustainability problems

<table>
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<tr>
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<td>x3</td>
<td>x9?</td>
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<td>x1</td>
<td>x3.5</td>
<td>x12?</td>
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<td>x4</td>
<td>x16?</td>
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<tr>
<td>Meat</td>
<td>x1</td>
<td>x5</td>
<td>x25?</td>
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<tr>
<td>Soja</td>
<td>x1</td>
<td>x8</td>
<td>x50?</td>
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<tr>
<td>International trade</td>
<td>x1</td>
<td>x10</td>
<td>x100?</td>
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<tr>
<td>Fish stock</td>
<td>100%</td>
<td>10%</td>
<td>extinct?</td>
</tr>
<tr>
<td>Global footprint (measured in planets)</td>
<td>0.5</td>
<td>1.3</td>
<td>3.5</td>
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- At world level, population is growing. This thrives consumption, which causes an increasing environmental pressure due to manufacturing and production.\(^{86}\)

- At the same time, urbanisation takes place and wealth is growing, around 80\% of the world population still lives on less than 10 US$ per day (Ravallion et al. 2008) and legitimately demands higher consumption in the future. More developed regions have a higher uptake of materials. People in industrialised countries consume up to twenty times more materials than people in least developed countries\(^{87}\); see Figure 98. Emerging economies, such as in Asia and

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\(^{86}\) Demographic trends underlying the issue of sustainable production are similar to that of Climate Change – via a similar mechanism of increasing consumption and associated higher uptake of resources such as energy. Please consult the document on climate change for more details.

\(^{87}\) Resource use and resource productivity in Emerging Economies: Trends over the past 25 years. SERI Working Paper 11, UN Industrial Development Organisation (UNIDO), Vienna
South-America, will drive strong growth of resources use. Please note that the EU does succeed in bringing down material use per added value (see section on economical drivers).

Figure 98 Material consumption of different world regions in tonnes per person (2000)

- When zooming in on Europe, demographic trends also cause growing consumption – although population growth, growing wealth and urbanisation are less important:
  - Consumption is shaped by the size of the population. **Europe’s population growth will level off until 2035 (growth primarily caused by migration) and decline after that.** The expected slowdown of growth and decline after that is expected to help curtail increases in resources consumption (SOER, 2010). Growth until 2030 will drive the total household consumption. The decreasing population of the EU can however be influenced by migration.
  - **Ageing will influence patterns of consumption, although the effects remain uncertain.** The share of household expenditures on food generally increase with age, as retired people have lower income which is spend on basic goods such as food. Moreover, ageing will lead to reduced disposable incomes and slower income growth. On the other hand, as baby-boomers are relatively wealthy and healthy, it lead to higher consumption of leisure and travel, with negative impacts for the environment.
  - There is a trend towards smaller and therefore more households. This leads to higher demand for space, building, and increases consumption of goods. One-person households
consume on average 38% more products, 42% more packaging and 55% more electricity per person than four-person households.  

- **As Europe does not have the largest stocks of materials, it will increasingly rely on foreign resources.** Given the increasing consumption and given that the EU already has the highest net imports of resources per person (SOER, 2010 & SERI et al. 2009), the import of resource will grow in future. Without major changes over the next 20 to 30 years, approximately 70% of the EU's energy will have to be imported. This is 20% more than today. In 2008, European imports of raw material amounted to 1,800 million tonnes, which is about 3.5 tonnes per person (SOER, 2010). Europe is substantially depending on imports from other countries, in particular for fossil fuels and metal ores; and will increasingly be dependent.

**E.1.2 Technological**

- **Technology and innovation has a two-fold, opposing role for sustainable production.**

  In the last decade, great efforts have been made to make industrial production more sustainable. This is shown by the decrease in resource intensity over the last decades (see economical).

  Eco-innovation is a pathway towards increased efficiency. Eco-innovation is any innovation that reduces the use of natural resources (including materials, energy, water and land) and decreases the release of harmful substances across the whole life-cycle. When asked what the relevance was of implemented innovations in terms of eco-efficiency, 56% of the respondents to the Eurobarometer survey reported more than 5% savings.

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Figure 99  material efficiency gains due to eco-innovation

Source: Eurobarometer 2011; graph by Eco-innovation observatory, 2011.

- **On the other hand, new technologies and innovation caused higher uptake of resources.** Technology and innovation changed our lifestyles: emergence of convenience foods, household appliances, ICT, etc., have changed our patterns consumption including mobility, food consumption etc., when compared to those of only one generation ago\(^90\). But even “green” technology development can lead to increased environmental impact via so-called **rebound effects**. Rebound effects exist as direct or indirect effect; it means that the positive aspects or other aspects of the eco-innovation lead to behavioural change that offsets the positive effect of the eco-innovation.

- Given the increase of resource efficiency and the lowering resource intensity of our society, the EU can play a significant role in making the first steps towards making available innovations that can increase sustainability of production. As most increase in resource uptake is to be expected in emerging economies (also while producing goods for the EU), resource efficient technologies can start in the EU.

- There are several visions of a resource-efficient Europe, such as presented in the 2010 Annual report of the Eco-innovation Observatory and in Bringezu (2009)\(^91\). We here present a concise overview of systemic technological changes these visionary reports identify as vital for future sustainable production:

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- Stabilisation if the net physical growth (infrastructure and building) through better reuse (renovation) and recycling (urban mining);

- Drastic reduction of primary resource extraction, e.g. enabled by smart metering;

- Steady increased harvest of biomass for food, utilising sustainable practices on cropland;

- Better use of sunlight for power and material production; going towards recycling of carbon capture from air by ‘industrial photosynthesis’92.

- Food and beverages, housing and infrastructure and mobility are the sectors which currently put the largest environmental pressure (see section E.1.393). The following technological trends are foreseen in these areas93:

  “Smart devices, such as intelligent appliances, floor tiles with embedded sensors, and biosensors could change the way we use appliances and heat and cool our homes. Full wireless broadband access for all households and rolling out of radio frequency identification (RFID) technology, which are expected to enable people to instantly connect to each other using tiny screens, digicams, video graphic messages, are just some examples. Mobile phones are increasingly used as digital terminals for data, text and media at declining costs. These new options might further encourage more working from home (JRC/IPTS, 2008) that could have the positive environmental impact of reducing commuting, but the effect is not clear-cut because people might accept longer commuting distances if they do not have to commute every day” (SOER, 2010).

  Moreover, smart metering and sensing might improve industrial processes and its efficiency drastically.

E.1.3 Economical

- Economic growth will lead to higher consumption, which, in turn will lead to higher production. The most important factor influencing consumption patterns is the level of disposable income at the individual household level94. The majority of environmental pressure of unsustainable

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92 i.e. generation of power out of sunlight and CO2 from the atmosphere.

93 We deliberately ignore infrastructure and mobility, as this will be part of the Grand Challenge of mobility and transport.

94 OECD, 2008. OECD Environmental Outlook to 2030.
production can be allocated to three main categories: Food and beverages, housing and infrastructure and mobility.\textsuperscript{95}

- Our society is increasingly service-oriented; production is often shifted towards other countries. As an effect of globalisation, \textbf{environmental pressure due to unsustainable production is distributed across the world}. As a result, a large share of our resource consumption is attributed to foreign countries. Europe is leading in shifting environmental costs of resource use abroad. From 1960 to 2005, the growth of traded goods has increased about 3.5 times whereas the associated \textit{hidden flows} (called ecological rucksacks) have multiplied by over 4.5\textsuperscript{96}.

- Making products cheaper is a competitive advantage. Almost 90\% of respondents from industry expect material cost to increase (EIO, 2011) – saving of resources will thus be a plausible cost reduction strategy. \textbf{Decreasing the production costs can be realised by decreasing the input by streamlining the production process and the product itself, which brings along savings in energy and materials.} According to the Eurobarometer survey, the most important driver for eco-innovation is the expected high price of energy and the current high price of materials and energy.

- The EU economy is already succeeding to bring down the material use and its negative impacts when compared to economic growth (see Figure 100). The average material productivity was 1,513 €/tonnes in 2007 compared to 1,213 €/tonnes in 2000\textsuperscript{97} – \textbf{the added value per material used will rise over time.} (Eco-innovation Observatory, 2011). The EU thus made a crucial step with \textit{decoupling} economic growth from resource consumption – although increasing consumption offsets this.


\textsuperscript{97} In comparison to other OECD countries, the EU has a material productivity similar to the United States (1,316 € in 2005, up from 1,187 € in 2000), but much lower than Japan (2,114 € in 2005 up from 1,593 € in 2000).
E.1.4 Political

- At the highest level, the Europe 2020 strategy gives useful guidelines for future growth of the EU. This includes three types of growth that will be strengthened, including a knowledge-based economy (which is depending on material and energy use to a smaller extent), sustainable growth (aiming at greening and resource efficiency) and inclusive growth (focussing on people, employment and social cohesion). In line with this strategy it is thus likely that policy attention for sustainable production will increasingly shift towards eco-innovation and resource efficiency (see or instance: resource efficient Europe (EC, 2011), or the ex-ante impact assessment of the Eco-innovation Action Plan (EC, 2010) (Technopolis & Wuppertal Institute, 2010)). This is likely to stimulate a further decoupling of economic growth from material use.

- Apart from environmental policy considerations, sustainable production and associated resource efficiency is also driven from other policy domains. Resource efficiency is increasingly gaining attention in Europe and policy processes will be launched to address the threats of potential supply disruptions, as was done with the so-called Raw Material Initiative (EC 2008). Material security, including security of supply and access to the material resources on which economies depend, as well as the ability to cope with volatility, increasing scarcity and rising prices are important facets for the well-being of European industries.
E.2 Problem analysis

Production of goods, products and services brings along high energy and resources consumption and often environmentally unsafe emissions. Although resource efficiency per unit (€) produced has increased over the last decade; increased consumption per person off sets this effect. Future drivers for increased consumption are demographic (growing population, urbanisation, ageing and fewer people per household) as well as economic (growing wealth). Meanwhile, production of goods has often shifted towards lower-cost countries and European economies are increasingly service-oriented. As a result, European resource use is often imported and therefore not within direct policy control.

Technology has a two-sided role for sustainable production. On the one hand it will enable more efficient production by making processes more efficient and by products that consume less resources. On the other hand innovation leads to more resources (wealth, time) that drive consumption, which brings along higher demands for resources. This demands sustainable production to offset the expected growth in consumption.

Food and beverages, housing and infrastructure and mobility are the sectors with the highest environmental impact. The potential for integrated systems is high in these sectors. The efficiency in these sectors can be increased by means of all different types of smarter organisation of processes: smart sensors can play a large role for more intelligent appliances. Improved biointerfacing and biosensoring could change the way we use appliances and cooling and heat our homes. Improved communication devices could improve ways to work from home, or to attends less meetings, thus decreasing the need for physical mobility. Moreover, smart metering and sensing can play a large role in making industrial processes more efficient.

E.3 Sources

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### Policy documents

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Appendix F Sustainable mobility

Mobility, the movement of people and goods, is fundamental to our economy and society. Effective transportation systems are essential to prosperity, having significant impacts on economic growth and social development, and mobility is an essential right of citizens. However the transportation networks that provide mobility have a considerable impact on the environment. Therefore the EU defines sustainable mobility as transportation systems that meet society’s economic, social and environmental needs.

This report addresses the drivers and trends that will impact on future transportation on networks 5 to 10 years in the future. It looks at all modes of transportation except air travel.

F.1 Trends and drivers

F.1.1 Societal

Demographic changes: more people, older people, bigger cities

Demographic shifts in developed and developing countries are changing the patterns of use, and therefore the requirements of, transportation networks.

At a worldwide level, growth in population by itself will put growing strain on existing infrastructures and create pressure for increases in capacity – in terms of both increased people and goods (to meet their needs) on the transportation networks. World population is projected to grow from 6.9 billion in 2011 to nearly 9 billion in 2050 and although the birth rate is beginning to decline, world population is forecast to continue to grow until at least 2040. The strain will be particularly severe in sectors where the available resources are limited (e.g. water services) or where there are physical limits to the extension of the network (e.g. roads). This not only places significant strain on business models that rely on effective and efficient

99 White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, COM(2011) 144 final
100 In the UN’s medium growth rate forecast; U.S. Census Bureau & UN Department of Economic and Social Affairs report: World Population To 2300 (2004)
101 UN’s low growth rate forecast (ibid)
transportation networks, but also on the business models underpinning the development and use of the transportation networks themselves. This problem is a major one for developing countries, since this is where population growth is expected to be the greatest and existing transportation infrastructures the weakest.

Urbanisation is a major trend in all countries, but will accelerate in developing countries as populations increasingly shift from the countryside to towns and cities. The trend towards urbanisation is expected to continue with 55% of world population in urban areas in 2020 and 65% in 2040. This movement of people also concentrates leads to a greater concentration of economic activity in urban areas. Currently in Europe more than 60% of the population lives in urban areas, and these areas account for 85% of EU GDP. This population shift increases demand on already highly used urban transport networks and will influence the design of transport networks of the future. The concentration of economic activity in urban areas has led, for example, to an increase, in developed countries in particular, in commuting time and distance. The size and economic sphere of influence of cities extends the average distance between people’s homes and workplaces.

In the developed countries, the demographic shift towards an ageing population will change market demand and mobility behaviour. In 2020 more than 25% of the European population will be older than 60 years and about 70% will live in urban and suburban agglomerations. Patterns of mobility vary with age - the number, length, frequency of trips made and mode of transport used differ across age groups. Therefore the age distribution of a population impacts on the requirements for mobility. This age profile of developed countries is expected to be repeated in developing countries as their GDP per head increases.

**Increasing individualisation: more households, more personalised products and services**

The general societal trend is for larger numbers of smaller households and an increasing individualisation of society. This leads to different social structures: the traditional family unit is already becoming less of a dominant feature of Western societies, with single households becoming more commonplace. This trend is linked to the increasing individualisation which has changed the dynamics of Western societies over the last few decades and continues to lead to changes in the patterns of daily life of citizens – the way they live, the way they work, the products and services they buy, the way they communicate etc.

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102 World Urbanization Prospects: The 2007 Revision Population Database, United Nations Department of Economic and Social Affairs

103 Robert Phaal, Foresight Vehicle Technology Roadmap - Technology and Research Directions for Future Road vehicles, Centre for Technology Management, University of Cambridge, 2002
Household structure is an important driver for the overall mobility of the population, as each household is the typical unit for car ownership and so more households means more cars on the road.\textsuperscript{104} This also has impacts on the mobility requirements of individuals – they may travel less to work, for example, but travel more for leisure – and on the physical supply and transportation of goods and services to meet their needs. This later effect on patterns of consumption will have an impact on the ways in which businesses innovates and markets new products and services to consumers.\textsuperscript{105}

The trend towards a stronger integration of customers into the design process whereby some customers may become co-inventors and designers of products is likely to extend to the design of vehicles. Individuality will not be limited simply to the appearance or design of a car, but also to its electronics and software to enable the specification of a car to meet the individual demands of a driver. The car of future will have individual “character”, it will recognise its owner/driver, be able to adapt, listen and understand, it will have personalised displays as well as transmission control systems that are capable of learning.\textsuperscript{106}

**Fading borders: decreased geographical boundaries**

The on-going process of globalisation is important driver for the trend of *Fading Borders*, i.e. the declining and blurring of geographical and conceptual borders and of the limits between and within globalised societies. This causes increasing interdependencies, complexity and more interwoven influences of capital and markets. The effects on both national and the global economy are tremendous.

Globalisation is leading to new ways of organising production and distribution. Organisational and technological innovation are creating extended and networked enterprises that are an integral part of the network-economy. These networks are increasingly international in scale and scope. New international business models and new organisational structures and new approaches to the way we organise work and our workplaces will emerge. It will lead to an intensified exchange of people and goods, and thus an increase in demand for mobility.\textsuperscript{107} There, of course, are feedbacks between transport and organisational models: efficient and low cost transportation is an enabler of networked organisations and people, and such networks place increased demands for mobility. Increased globalisation has already had a significant

\textsuperscript{104}
\textit{TRANSvisions}, Final Report: Report on Transport Scenarios with a 20 and 40 Year Horizon, March 2009, Coordinated Tetraplan A/S, Copenhagen, Denmark

\textsuperscript{105}
\textit{Megatrends: a broad outlook on innovation}, TNO, 2010

\textsuperscript{106}

\textsuperscript{107}
\textit{Megatrends: a broad outlook on innovation}, TNO, 2010
impact on the volume of international freight transport and this trend is expected to continue.

F.1.2 Economics

**Economic Growth: more consumption and changes in patterns of consumption worldwide**

Economic growth is in itself a driver for increased transportation and mobility of people and goods. It not only increases levels of consumption and demand for goods but, in developing countries in particular, economic growth and development leads to changes in mobility levels and patterns as citizens consume more, work less and have more disposable income. The link between transport and economic growth is of course two-way, economic growth increases demand for transportation, but equally, effective transportation networks are essential for economic growth. Similarly economic and social factors are inter-related: roads create cities as well as cities create roads. Demand for transport is driven by social relations and economic activities but transport also enables social relations and economic activity. 108

Economic growth means greater consumption of goods (intermediate and finished) and services and greater wealth is correlated to higher levels of personal travel and higher rates of car ownership. Furthermore economic growth tends to reduce infrastructure costs, including transport, as labour and capital are deployed more effectively. All these combine to increase the levels of freight and personal mobility. Figure 101 shows the (historical) close relationship between GDP and transportation.

Despite the current economic downturn growth is expected to continue, albeit at different rates in the developed and developing worlds. The IMF forecasts worldwide GDP annual growth to be 4.5-4.7% from 2012 to 2016. In advanced economics the figure is 2.4-2.6% although it is a little lower in European Union at 2.1-2.2%; while emerging and developing economies are forecast to grow at 6.4-6.7% and as much as 8.6% in developing Asia which includes China (but not India). 109

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The increase in demand for transportation in the EU is forecast to be 1.4% per year in passenger-kilometres and 1.7% per year in freight tonnes-kilometres between 2005 and 2030 (Figure 102). In the USA freight transport is forecast to almost double from 20,000 tons to 37,000 tons between 2008 and 2035.\textsuperscript{111}

Economic growth is not only a major driver of the demand for transport infrastructure, but changes in the composition of output also have a bearing (e.g. growing share of services in overall consumption) on infrastructure usage patterns.\textsuperscript{112}

\textsuperscript{110} Reported in TRANSvisions, Final Report: Report on Transport Scenarios with a 20 and 40 Year Horizon, March 2009

\textsuperscript{111} U.S. Department of Transportation, Freight Facts and Figures 2009, Coordinated Tetraplan A/S, Copenhagen, Denmark

\textsuperscript{112} Infrastructure to 2030 Volume 2 – Mapping Policy for Electricity, Water and Transport, OECD, 2007
Globalisation: more goods and services traded internationally

The world economy is increasingly inter-connected – capital, labour, goods and services flow across national boundaries at ever greater levels. This globalisation is leading to new ways of organising production and distribution, that rely on efficient supply chains and effective logistics. While this can lead to complex networks of supply it has also enabled the concentration of production in fewer factories and large scale highly-centralised distribution processes. New production methods such as just-in-time manufacturing combined with reduced transportation costs and developments in information and communications technologies have made it cost-effective to centralise production and minimise inventory holdings stock holdings. Conversely the same drivers, have enabled retailers, both ‘real’ and on-line, to centralise stock-holding into large distribution centres that, again, increase transportation miles but at a lower overall cost of supply distribution. The effect of these strategies in terms of transportation mileage is variable with some reducing over all transportation miles per product /service and others increasing miles.

The growth of world trade, and in particular since 1990, has led to growing share of long distance trade: more goods were and are still transported over long distances than before. As a result the freight transport volume has grown in recent years faster than GDP.

Despite the current economic downturn globalisation is forecast to continue. As is the case for economic growth, globalisation is both a beneficiary of effective transportation networks and a driver of increased demand for efficient transportation. However the exact nature of the future of globalisation is highly dependent on the availability of low-cost transportation, and the trend for ever-decreasing transportation costs is limited by two factors: increased transport network congestion as volume increase which increase travel time (and therefore costs) and the costs associated with minimising transportation’s impact on the environment.

Environmental/ Ecological

113 Reported in TRANSvisions, Final Report: Report on Transport Scenarios with a 20 and 40 Year Horizon, March 2009
114 Ibid.
115 Ibid.
116 Ibid.
Reducing the emissions of greenhouse gases from transportation is an essential feature of sustainable mobility. Transportation, road transportation in particular, makes a significant contribution to emissions of CO$_2$. Transport is responsible for around a quarter of EU greenhouse gas (GHG) emissions making it the second biggest greenhouse gas emitting sector after energy. Road transport alone contributes about one-fifth of the EU’s total emissions of carbon dioxide (CO$_2$), the main greenhouse gas (Figure 103). Even though emissions from civil aviation or total navigation have been growing faster than those of road transport in recent years, road transport still accounts for more than 70% of all transport emissions.\textsuperscript{117} While emissions from other sectors are generally falling, those from transport have increased 36% since 1990.\textsuperscript{118}

EU leaders have a unilateral commitment Europe would cut its emissions by at least 20% below 1990 levels by 2020. Furthermore, the EU has offered to increase its emissions reduction to 30% by 2020, on condition that other major emitting countries in the developed and developing worlds commit to do their fair share under a future global climate agreement.\textsuperscript{119} Furthermore the Commission reports that to limit climate change to below 2°C will require reducing emissions even further - by 85-90% of below 1990 levels by 2050.\textsuperscript{120}

Figure 103: Distribution of GHG emissions by transport mode in the EU-27, 2007

\textit{Data source: European Commission, 2010 (based on EEA data, July 2009)}

\textit{Note: GHG emissions from railways excluding indirect emissions from electricity consumption}

\textsuperscript{117} T. Wiesenthal et al., Research of the EU automotive industry into low-carbon vehicles and the role of public intervention, JRC Technical Notes, 2010

\textsuperscript{118} European Commission - Climate Action: http://ec.europa.eu/clima/policies/transport/index_en.htm

\textsuperscript{119} European Commission - Climate Action: http://ec.europa.eu/clima/policies/brief/eu/index_en.htm

\textsuperscript{120} European Commission White Paper: Roadmap to a Single European Transport Areas – Towards a competitive and resource efficient transport system, COM(2011) 144
These targets impact on transportation in two ways:

Firstly, emissions from vehicles has to be reduced. The European Commission’s goal for transport emissions is a reduction to around 20% below 2008 levels by 2030.\textsuperscript{121} It has a comprehensive strategy to reduce CO\textsubscript{2} emissions from new cars and vans sold in the European Union. The strategy adopted in 2007, aims to tackle CO\textsubscript{2} emissions from both the production and consumer sides and is designed to help the EU reach its long-established objective of limiting average CO\textsubscript{2} emissions from new cars to 120 grams per km by 2012 - a reduction of around 25% from 2006 levels.\textsuperscript{122} Although this goals is unlikely to be achieved the strategy, and the measures it includes, has played an important role in reducing CO\textsubscript{2} emissions from light-duty vehicles to date. The Commission is currently assessing the feasibility of a target, proposed by the European Parliament of reaching 70gCO\textsubscript{2}/km by 2025. Reducing emission from vehicles will be achieved, in the short-term, through improvements in the fuel efficiency of vehicles powered by fossil fuels and, in the longer-term, by a transition to alternatively fuelled powertrains such as electric vehicles fuelled by batteries and hydrogen fuels cells.

Secondly, transportation emission reductions can be achieved through a shift in transportation modes – from roads to public transport for passengers and from roads to rail for freight.

\textbf{F.1.3 Political}

\textbf{Transport Legislation and Regulation}

The European Commission has a commitment to both an integrated transport network within Europe and to the reduction in emissions from transportation. The Commissions’ 2011 Transport White Paper aims to improve the flow of passenger and freight within Europe in pursuit the territorial cohesion of the European Union, while managing the growth in transportation in support for economic growth and meeting its own targets for a 60% reduction of greenhouse gas emissions from transportation.\textsuperscript{123} The white paper specifically refers to the need to ‘break the transportation systems’ dependence on oil with sacrificing efficiency or compromising mobility.’ Further more it recognises that curbing mobility is not an option.

\textsuperscript{121} Ibid.

\textsuperscript{122} European Commission - Climate Action: http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm

\textsuperscript{123} European Commission White Paper: Roadmap to a Single European Transport Areas – Towards a competitive and resource efficient transport system, COM(2011) 144
Furthermore in 2010 the European Parliament and Council finalised a directive (2010/40/EU) on a “framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport”\(^{124}\). The directive is focused on implementation of intelligent systems to track, monitor and manage traffic flow on European road networks and on interfaces between road transportation and other transport modes. The Parliament took the view that voluntary agreements and standardisation have failed to deliver significant progress in terms of deployment and use of such systems and the directive provides the legal framework for the implementation of the actions required for an effective and coordinated deployment and use of intelligent transport systems (ITS). It focuses on ensuring the compatibility, interoperability and continuity for the deployment and operational use of ITS.

**Geopolitics**

The increasing interdependence of nation states will, in the coming decades, create an environment where geopolitical relations will be more complex and involve a larger set of actors beyond nation-states. This will have important implications for infrastructure development as well as the management of common resources – requiring increased co-ordination across countries. This may lead to the formulation of transnational regulation and the establishment of transnational standards (e.g. water, road and rail transport).

Geopolitical factors will also be important in other ways beyond purely economic or social considerations. Transportation and communications networks will continue to be given high priority by government as a tool for nation-building (or regional integration) and for forging links with other countries – such as the TEN-T initiative to develop an integrated transport network in Europe and plans to expand it to 26 neighbouring countries.\(^ {125}\)

**Safety Legislation and Regulation**

Although casualties from auto accidents may be decreasing, they remain unacceptably high: road accidents kill more than 40,000 people in the EU each year, and injure nearly 2 million more, costing society about €160 billion.\(^ {126}\)

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\(^{125}\) Infrastructure to 2030 Volume 2 – Mapping Policy for Electricity, Water and Transport, OECD, 2007

\(^{126}\) EUFocus, September 2009
National governments and the European Commission have set targets to increase safety. For instance, the EU aims to reduce road deaths by 75% until 2020. The vision of an “accident-free driving” is therefore the ultimate long-term goal. Better managed traffic and more ‘active’ safety systems such as automated or assisted driving aids and predictive tools many help to reduce accidents and produce savings in terms of lives, damage and time. This may also lead to a trend where active safety will become more important than passive safety.

The Commission’s Intelligent Car Initiative, founded in 2006, has the objective to improve road safety in the European Union through the incorporation of ‘intelligent’ systems i.e. IT/sensors-based systems to control some vehicle functions and/or assist drivers. The initiative is also intended to reduce fuel consumption and road transport’s CO² emissions.

F.1.4 Technological

Technological trends that impact on transport fall into two categories:

- Technologies developed specifically for transportation applications. The most important of these are powertrains for vehicles (cars, trucks etc. but also for other transportation modes – rail, water, air) based on non-fossil fuels – such as electric vehicles based on battery technology or hydrogen fuel cells

- Underpinning or generic technologies that impact on transportation – the most important being developments in ICT that provide opportunities to improve the performance of both individual vehicles and the transportation infrastructure

**Technologies developed specifically for transportation applications**

Technological developments focused on low emission vehicles are being driven as much by environmental and legislative drivers as by technological developments. In many cases the technology development involves the deployment of an engineering solution to adapt and improve existing technologies for transportation applications – such as improvements in the efficiency of batteries or the development of smaller robust fuel cells, and the design of powertrains and infrastructure to support new energy sources.

However improvements in fields such as materials and chemistry underpin improvements in battery or fuel cell efficiency.

**Underpinning or generic technologies**

ICT has had a significant impact on transportation and mobility. The incorporation of ICT into vehicles and infrastructure has improved the performance of both and enabled new approaches to travel at both the
personal and network level. New cars are predominantly managed and controlled by electronic devices; small scale GPS devices have changed the way we navigate; and real-time traffic management and road user charging systems would not be possible without the development of smaller and cheaper and more sophisticated ICT-based devices and systems.

The incorporation of ICT in vehicles and infrastructure will continue to increase, driven by:

- The **miniaturisation** of devices and systems that offer higher performance at an ever decreasing size and price. Miniaturisation is, on one hand, a result of the progression of Moore’s Law that increases computing power of microchips with no subsequent increase in size or price, and on the other the decrease in size of sensors and actuators that monitor physical attributes and control systems (the airbag sensor is already based on nanotechnology for example). Here miniaturisation is driven by new sensing techniques (such as optical devices) and nanotechnology that increases the range of attributes measurable at a scale and price suitable for incorporation in vehicles and infrastructure. Importantly miniaturisation, in parallel with increased performance, increase the potential to embed ICT in transportation, not only to manage the vehicle but also to measure a wide range of attributes and communication them to other vehicles and to the transportation infrastructure itself. The information provide in this way provides opportunities to manage transportation flow more effectively and efficiently. Miniaturistaion is predicted to continue; in microprocessors, for example, the current progression of Moore’ Law is predicted to reduce individual components to the single of a few atoms by around 2020.

- The development of **improved wireless communication architectures and infrastructures** has allowed communication of information beyond the telephony and the internet to communication between devices. This increase opportunities for automation of a whole range of management and control systems. Both short and long range communication technologies and protocols have been, and continue to be, developed and which, based as they are on miniaturised technology, can be embedded in an ever-increasing range of objects. The concept of an ‘internet of things’ where large numbers of every-day objects are wirelessly connected together is still a long way off but individual systems to control and manage interconnected objects and systems already exist such as road-user charging (e.g. distance based charging for lorries in countries such as Germany and Austria and charging for all vehicles in London) and traffic flow identification and information systems.

- Improvements in the **management of large, complex and distributed data** is driven not only by increased computing power but also new architectures to manage and utilise data across distributed
networks, such as GRID computing, and efficient algorithms for computations.

- Developments of ‘intelligent or ‘smart’ systems that gather and integrate data from a number of sources (sensors, databases etc.), conduct analyses in real-time, and take automated decisions in a predictive or adaptive way. Alternatively the decisions may be conveyed via effective interfaces to humans to assist them in their decision making. Such systems can be used at the level of individual vehicles for accident avoidance, automated or assisted driving and at the infrastructure level for optimal route, load exchanges for minimising empty freight vehicle movements and efficient transfer between transport modes (rail to road, road to rail etc.)

F.2 Problem Analysis

Economic growth and demographic shifts are placing an increased demand on transportation capacity (population growth, economic growth), creating different patterns of transportation use (urbanisation, networked businesses) and creating the need for improved access to transportation and mobility (ageing population and an multi-national integrated transport system). At the same time the environment impact of transportation has to reduce to meet emissions regulations and limit climate change. The potential to increase transportation capacity is limited, particularly in developed countries and particularly in urban areas, and therefore increased demand will have to be met through better and more effective use of networks and changes in mobility behaviours.

The challenges for sustainable mobility in the coming 5 to 10 years fall into three categories:

- Reducing transportation congestion in an era of increased transportation activity and ensuring that goods and people can keep moving in pursuit of economic, social and personal goals
- Achieving the above while reducing the environmental impact of transportation
- Increasing the safety of transportation

Within the EU and surrounding countries there is the additional challenge to inter-connect transport systems across all modes (road, rail sea etc.) across national borders.
These challenges disaggregate into three areas: 127

- Optimising the use of transportation infrastructures, especially roads, through real-time information on use and incentives to modify mobility and transport behaviours
- Developing and deploying new propulsion systems based on sustainable fuels and optimising fuel efficiency in use
- Optimising performance of multi-modal logistics chains and passenger journeys (road-to rail to sea etc.) to ensure greater use of the most energy-efficient modes

Many applications depend heavily on the deployment of ICT devices and systems:

- Real-time multi-model transport information systems delivered to individual users to optimise transport mode and route selection.
- Real-time multi-model transportation information systems for optimisation of the flow of people and goods and reduction of emissions. A particular focus is information and logistics solutions that maximise the inter-change between modes for long-distance and short distance travel e.g. energy efficient rail and mega-trucks for long-distance combined with electric vehicles for short-distance transportation.
- Assisted and automated accident avoidance and vehicle control systems e.g. automated vehicle-to-vehicle distance and/or speed control on motorways, fuel management and to support older or disabled drivers.
- Automated road-user charging to optimise flow and reduce emissions. Such systems can be based on distance travelled, time of day, type or weight of vehicle or even level of pollution (‘polluter pays’ models).

F.3 Sources

Sources with relation to the grand challenges have been taken up in the text, as a footnote.

127 This list is based on (and adapted from) the European Commission White Paper: Roadmap to a Single European Transport Areas – Towards a competitive and resource efficient transport system, COM(2011) 144
Further sources interesting for the application of IMS in sustainable transport are:


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