The European Photonics Industry represented by Photonics21 handed over the Photonics PPP Multi Annual Roadmap “Towards 2020 - Photonics Driving Economic Growth in Europe” to Vice President of the European Commission Neelie Kroes at the Photonics21 Annual Meeting 2013. By doing so the European Photonics Industry made a strong commitment to significantly - up to 5.6 billion € - invest in Research, Innovation and Manufacturing in Europe by matching every Euro spent by the European Commission in the PPP with 4 € by Industry.

Figure 1: Handing over ceremony of the PPP Roadmap to Vice President Neelie Kroes by the Photonics21 of the European Commission Executive Board
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Part I: Vision

Introduction

The Photonics PPP represents a long-term commitment between the European Commission and the Photonics Stakeholders to invest in Europe with the aim of securing Europe's industrial leadership and economic growth in photonics, a highly skilled workforce, and the capability to generate new jobs that attract young people. The PPP will be the basis for a Research and Innovation strategy and more broadly for an industrial strategy in photonics for Europe for the next 7 years.

Photonics is everywhere around us: from communications and health, to materials processing in production, to lighting and to everyday products like DVD players and mobile phones. Yet the full disruptive potential of photonics is only now becoming clear.

Photonics is a fast-growing business sector, with a global market of around €350 billion, projected to reach over €600 billion by 2020\(^1\). Europe has established a strong position with an overall total share of approximately 18%\(^1\) (€66 billion\(^2\) in 2012 – see Figure 2). Major growth is expected in lighting, medical technologies and life sciences, laser-based manufacturing and optical communications. These are the areas where the European Photonics industry is particularly strong.

World Market Share for Key European Photonics Industry Sectors:

- Production Technology: 55 %
- Optical Components and Systems: 40 %
- Image Processing and Metrology: 40 %
- Medical Technology and Life Sciences: 30 %

\(^1\) SPECTARIS, VDMA, ZVEI, BMBF, ‘Photonik – Branchenreport 2013’, May 2013
\(^2\) EPIC/TEMATYS Report ‘Photonics Ecosystem in Europe’, April 2013
The European photonics industry employs more than 300,000 people directly, many of these in the over 5000 photonics SMEs often structured in national and regional innovation clusters which represent a highly educated workforce. Photonics also has a substantial leverage effect on the European economy and workforce: 20-30% of the economy and 10% of the workforce depend on photonics.

Photonics is a very dynamic and vibrant industrial sector in Europe that holds the potential for huge market growth. The expected compound annual growth rate for photonics over the coming years is 8%, clearly demonstrating the rapid growth of this key technology sector. In specific areas, substantially higher growth rates are predicted, for example, in green photonics the expected CAGR value is nearer 20%. A detailed analysis about the present status of the photonics sector in Europe and its future development and market perspectives was provided in the main KET6 and Photonics7 specific reports.

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3 Figure adapted from EPIC/TEMATYS Report ‘Photonics Ecosystem in Europe’, April 2013
5 European Commission’s study SMART 2009/0066 - The leverage effect of photonics technology: the European perspective.
SWOT analysis for Photonics in Europe

In addition to these studies an extensive SWOT analysis was carried out in the frame of the Key Enabling Technology initiative. The findings are presented in the table below, and outlined as follows:

- Europe has a strong research and innovation (R&I) eco-system in photonics with world leading research organisations, companies and national and regional innovation clusters. The European Photonics stakeholders are very well organised around the Photonics21 European Technology Platform with about 2000 members.

- Photonics is a very dynamic and vibrant European industrial sector. It has market leaders in core industry areas, established links with application industries, a highly diversified SME industry and a highly educated workforce.

- This market share is threatened by globalisation via low-cost off-shore manufacture and competition from the Far East encouraged by more favourable investment, State Aid and IPR conditions. Moreover, there is fragmentation of R&I initiatives in Europe. Europe also suffers from a slow innovation process and lack of significantly sized demonstration and commercialisation actions to accelerate transfer from laboratory to market. This means Europe's technology leadership is not utilised optimally and good research results are not turned into innovative products ('Valley of Death'). There is also limited access to Private Equity (seed) money and capital to finance industry, in particular innovative SMEs.

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<th>STRENGTHS</th>
<th>WEAKNESSES</th>
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<tr>
<td>S1. Established technology leaderships</td>
<td>W1. Fragmented and uncoordinated development strategy, particularly for EU funding strategy along the value chain</td>
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<tr>
<td>S2. Strong European research ecosystem with world-leading research organizations, companies and clusters</td>
<td>W2. Slow innovation process and lack of significantly sized demonstration and commercialization actions to accelerate transfer from lab to market</td>
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<td>S3. World market leaders in core industry areas</td>
<td>W3. Limited access to Private Equity (seed) money and capital to finance innovative SMEs</td>
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<td>S4. Established links with application and user industries</td>
<td>W4. Limited public (pre-competitive) procurement for speeding up market uptake of innovative products</td>
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<td>S5. Highly diversified SME driven industry</td>
<td>W5. Unfavourable IPR conditions and European State Aid Rules in the EU</td>
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<tr>
<td>S6. Highly educated workforce</td>
<td>W6. Lack of skilled engineers will limit expansion of industry</td>
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<td>S7. Wide applications space</td>
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<th>OPPORTUNITIES</th>
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<td>O1 Photonics provides competitive advantages to vital manufacturing industries in Europe</td>
<td>T1. Low-cost off-shore manufacture</td>
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<tr>
<td>O2 Rapidly growing market place</td>
<td>T2. Increasing competition, especially from the Far East in nearly all photonics sectors</td>
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New advances in photonics will move communications into the terabit era by dramatically increasing data capacity and data transmission speeds while simultaneously reducing the networks’ carbon footprint and the overall cost per bit. Photonics technology will help overcome the limitations of electronics in computers through all-optical computing (or even quantum computing). In manufacturing, laser processing will be a basic prerequisite for high-volume, low-cost, zero-defect manufacturing. Photonics will revolutionise healthcare and provide new ways of detecting, treating and even preventing illness. Photonics will play a key role in addressing the challenges of energy efficiency and moving to a low-carbon economy. In the future, solid-state light sources are expected to outperform almost all other sources in terms of efficiency, offering potential energy savings of 50% or even more when used with intelligent light management systems. Sensor applications in smart power grids, smart buildings and smart industrial process control will contribute significantly to more efficient use of resources and meeting environmental challenges.

In September 2009 the European Commission designated photonics as one of six key enabling technologies for our future prosperity. This signifies not only the economic importance of photonics, but also its potential to address what have been called the ‘grand challenges’ of our time that could have major potential impact on Europe’s prosperity and sustainability. These challenges are: ensuring sustainable development, securing energy supply, addressing the needs of an ageing population, and ensuring human and environmental health. In addition to these challenges, a key focus must be to achieve secure employment across Europe over the coming years.

The European Photonics Industry has established technological expertise and capabilities that have resulted in its world leadership in several key industry sectors:

- Lighting
- Healthcare
- Manufacturing
- Optical Components & Systems

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8 COM(2009) 512 final of 30 September 2009
Photonics offers vital contributions to fundamental societal challenges

Photonics has a critical role to play in addressing several of the grand challenges identified in the Europe 2020 strategy.

Towards a sustainable economy - Green Photonics

‘Green photonics’ is the term used to encompass the application of photonics technologies that can generate or conserve energy, cut greenhouse gas emissions, reduce pollution, yield environmentally sustainable outputs, or improve public health. Green photonics covers a broad range of photonic technologies and applications: highly efficient solid-state lighting (SSL), new energy-efficient communication technologies, and clean manufacturing using laser processing.

Green photonics is already a key technology for improving the global balance of atmospheric carbon dioxide and consequent global warming, and will become increasingly important in the decades to come. In spite of the recent recession the overall market demand for green photonics technology is expected to achieve a 2009-2020 CAGR of ~20%. So by 2020 such green photonics components are predicted to comprise over 54% of a $492 billion global optoelectronics market, representing over $250 billion. Significant optoelectronics drivers will be solid-state lighting, but there will also be strong growth rates in all eight green photonics technology segments.

These predictions show that green photonics will contribute significantly to increases in manufacturing industry volumes and so further stimulate employment. Europe needs to invest further in this vital technology to guarantee its competitiveness by supporting the next generation of green photonics solutions and applications.

Examples of how green photonics contribute to a sustainable economy are provided below:

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9 Rounded values taken from OIDA
**The case of Solid State Lighting:**

If we are to save energy and reduce emissions of carbon dioxide we will have to find more efficient ways to produce and consume energy, and photonics offers solutions to both. The green photonic technology expected to have the largest impact in the short term is light emitting diodes (LEDs and OLEDs) for energy efficient solid-state lighting. Indeed, in the near future, solid-state light sources are expected to outperform almost all other sources in terms of efficiency, offering potential energy savings approaching 50%. When solid-state lighting technology is then combined with intelligent light management systems that regulate light output according to ambient lighting conditions or people’s presence and activities, another 20% can be saved. Hence advanced solid-state lighting could dramatically cut present-day electricity consumption for lighting by about 70%.

The realization of these solutions will allow huge benefits to be achieved:

- each year more than €300 billion can be saved on the global energy bill by introducing energy-efficient lighting;
- as a result of this, emissions of more than 1000 million tons of carbon dioxide can be saved per year on a global level.

In addition:

- the economy will be boosted by strengthening Europe’s industrial position in lamps, luminaires & driver electronics.
- society at large will profit from greater visual comfort due to superior lighting solutions and from less light pollution through more closely focused light;
- energy-efficient lighting technologies will provide significant individual financial savings;

The McKinsey analysis on the abatement costs of carbon reduction stated that lighting offers the second largest potential for cost savings, close behind improved insulation. These technologies have reached a stage of development where saving carbon goes hand in hand with saving costs and improving competitiveness. It is clear that technologies associated with lighting offer the biggest opportunities to save energy in the short run, giving more time for the development of renewable energy sources in order to safeguard Europe’s energy independence in the long run.

**The case of clean manufacturing using laser processing:**

Lasers represent a versatile tool for handling a wide range of manufacturing tasks all along the workflow chain, from material processing through to quality control. For example, the ability of lasers to machine an ever larger range of materials allows fabricating lightweight, high-strength constructions.

Lasers play already a major role in facilitating green manufacturing, since laser processes allow for very precise, well-controlled and therefore resource-efficient and energy efficient deposition / processing on the work piece(s).

Typically the added value generated with a machine tool or a laser system, are calculated as a multiple of the cost of the tool itself. Taking due account of this factor, the laser processing industry on its own is a multi-billion Euro industry. It also has a substantial leverage effect on many other industries, most notably in the European automotive and aeronautics sectors.

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11 Pathways to a low-carbon economy; McKinsey & Company, 2009
In the future, laser processing capabilities will be extended significantly to enable many new and challenging applications, for example, processing of composites and dissimilar materials, additive manufacturing (e.g. ‘product printing machines’), mass production of individual items, colour marking, etc. They will also allow the fabrication and laser treatment of functional surfaces and advanced materials (biocompatible functional implants, nanoparticles, fibres for microelectronics, flat-panel displays, laser cleaning, surface hardening, and bonding of transparent materials).

Future laser-based processes will also allow reducing consumption of chemicals, for example, by replacing the chemical etching baths currently used for the manufacturing of rotogravure cylinders by a laser engraving process. They will increase the efficiency of photovoltaic devices and will enable energy storage devices with higher capacities; a key requirement for future electric cars.

Finally, the incorporation of adaptive reconfigurable beam delivery networks will allow higher power and intensity of lasers. This will lead to new applications, for example through the use of ultra-short laser pulses. These improvements will allow extending laser technology to large market sectors, such as electronic industries, particularly consumer electronics.

**Photonics for the Ageing Society & Healthcare**

Current projections indicate that by 2050 the number of people in the EU aged 65 or more will have grown by 70%, and for those in the 80+ age group this value increases to 170%. It is important that this ageing generation continues to play a full and productive part in our society. Unfortunately, as older people are more prone to illness and will need more long-term nursing care, global spending on healthcare will inevitably rise considerably in the coming decades. This will clearly have an effect on future generations, not least because the proportion of people in work and paying taxes will be falling as the overall population ages. However, this financial impact can be mitigated - the European Commission has estimated that the rise in healthcare spending due to ageing could be halved if people remained active and healthy in their later lives. Therefore support for actions and measures that promote health, prevent illness and provide solutions for the future healthcare system in Europe will be essential.

It is estimated that two thirds of all diseases today, in particular including dementia and certain ophthalmic diseases prevalent in older people, cannot be treated by tackling their root causes. This is further compounded by the fact that many such diseases can only be diagnosed relatively late in their development and that prospects for successful cures of these diseases decline the later the diagnosis is confirmed. Consequently, there is a major requirement for improved diagnostic tools, capable of earlier disease detection, and for new techniques to provide more efficient treatments. Photonic technologies provide a vital addition to the tools that a doctor can use for the diagnosis of many severe illnesses and may also provide effective new treatments leading to early stage cures, thereby avoiding costly long-term treatments. Such early diagnosis using photonic technologies will help prevent illness and so have a beneficial effect on patient health, on the healthcare system and hence on society. The application of photonics in healthcare has been estimated to offer cost reductions of as much as 20%. As demographic change and the ageing society in Europe push healthcare costs upwards, the savings provided by photonics will be substantial and ultimately lead to significant improvements in the quality of life within our society.

Photonics can play a major role in this area for the following reasons.

- Innovative microscopes and endoscopes will help us to understand cell processes, tissues and model organisms and so support the development of drugs tailored to a given patient. These are urgently needed for personalized medicine.
Screening and medical imaging methods based on photonics will strengthen preventive medicine and the early detection of diseases.

Non-invasive or minimally invasive treatments, such as therapeutic laser systems, will help to improve the health and mobility of patients and could lead to substantial cost savings.

By combining micro-fluidics with photonics we can make ultra-sensitive ‘lab on a chip’ biosensors. These sensors can measure minute amounts of substances in small sample volumes, and make it possible to assess patients rapidly at the bedside (Point-of-care diagnostics).

As an example, cancer is one of the biggest challenges associated with the ageing society. Early detection of cancer is the key factor, since the earlier the detection the more likely a cure will be possible. A WHO study, for example, shows that 30% of all cancer cases could be cured if detected early enough. Photonic technologies are already applied relatively widely in laboratory testing for diagnosis, but their use for in-vivo diagnosis and treatment is limited to photodynamic therapy and to fluorescence endoscopy for detecting tumour lesions during surgery. This is likely to change within the next few years since photonic technologies offer clear advantages over established technologies such as X-ray and ultrasound: they have better resolution, are more specific and can produce results in real time. New diagnostic and treatment markets will emerge from innovative photonic technologies, especially by the combination of existing photonic and non-photonic imaging methods such as positron emission tomography (PET).

The world market for optical technologies in healthcare is €23 billion, and this is growing at 8% CAGR that will yield a market approaching €43 billion by 2015. The market for biophotonics is even larger at €70 billion. In 2008, European industries maintained their leading position with a 30% share in the worldwide biophotonics market. Europe produced €5.7 billion worth of photonics for medical imaging and life sciences in 2005, representing 33% of the corresponding world market and 13% of the entire European photonics production. Joint European research efforts and funding are strongly recommended in order to strengthen market positions in this critical photonics technology.

**Photonics for greener, ultra-broadband solutions for All Europeans**

The importance of the European digital sector has been increasing steadily since 2005, and Europe is now a global force in advanced information and communication technologies. These technologies accounted for 50% of the rise in EU productivity over the past four years. Today, the major highways for communication and information flow are optical using photonic technology. Data rates for accessing the Internet are continuously rising as the latest advances in lasers, optical fibres and optical coding technologies are deployed in the network. Bringing the benefits of broadband communications to European citizens is both the challenge and the reward for the next generation of photonic systems.

We all now depend on this photonic infrastructure for our communication, business and entertainment needs, and look forward to the next stages of its evolution, whether they are in new services, enhanced connectivity, lower costs, or ‘infotainment’. This evolution will be essential for a sustainable future. Genuinely broadband communications, available everywhere, will continue to revolutionise all aspects of society.

Computers and telephones are currently connected to the network by cable or wireless links, but just a short distance away these signals will certainly be transported optically. In the near future many of these 'short' distances will essentially become ‘zero’ distances, as photonic networks become increasingly embedded into our homes and work places, and even directly into the devices themselves. This increasing penetration of photonic technologies offers major benefits
in performance and costs to service providers, and represents a significant commercial opportunity for the photonics industry.

As the World Wide Web continues its rapid expansion, with Internet traffic growth currently exceeding 60% per year, photonic solutions for communication will become increasingly important, and the Internet, now recognised as being the largest machine in the world, will become a vast photonic engine. By 2020, the Internet will be used extensively with mobile appliances, linking mobile phones, computers, domestic appliances, machines and vehicles, and enabling an unprecedented level of interconnectivity. The deployment of these next-generation, ultra high speed photonic networks will initiate the development and application of exciting new products and services that fully exploit this connectivity, with huge potential impact on European society. This impact will be broad, contributing to increase a 1000-fold increase in optical bandwidth, facilitating optical networks, photonics integrated circuits, optical switching, optical interconnects, access networks, metro and core cross, connects in the data servers and data centres, ‘optical computing’, etc.

The worldwide telecoms market reached €2.4 trillion in 2008, a growth of 3.2% over 2007, and the projected growth profile predicts this market expanding to nearly €4.3 trillion by 2020. Within this, the market for optical networking equipment is currently of the order of €10 billion (of which photonic components made up €3 billion) and is projected to continue to grow to over €14 billion by 2020. Photonic technologies leverage a telecommunication infrastructure market worth €350 billion and impact more than 700,000 jobs in Europe12.

**Photonics for Safety, Security and Environmental Monitoring**

Europe’s open, democratic, welfare societies, combined with globalisation and the end of the cold war, expose us to several security risks such as organised crime, terrorism and trafficking in drugs, people and hazardous materials. People want to feel secure when they go into public buildings, airports, railway stations and other public spaces. Therefore, a primary focus must be on the safety of products, systems, buildings and infrastructures. Sensors and measuring devices play an important role as they enable us to detect dangers at a very early stage. Information and communications technology contributes to collecting and processing data to avoid dangers, and photonics will play a key role:

- In road transport, applications such as intelligent driver-assistance systems and night vision systems
- Improve safety for all road users. Driver-assistance systems in cars rely on photonic sensors to help avoid driving errors. If we further develop these photonic technologies, our roads will be even safer in future.
- The detection of unauthorised goods at airports and international borders is another important issue for public safety. Innovative photonic applications can help make such inspections more efficient. Biometric technologies, which also use photonics, can enhance safety and security at international borders.

The total world market for safety and security equipment using photonic sensing is €22 billion. The safety market accounts for €7 billion of this, made up of €2 billion for air pollution detection and €5 billion for the automotive sector. The security market accounts for the remaining €15 billion, and, with an expected growth of 15% CAGR. This represents a very attractive market that has grown to 75% of the size of the slow-growing defence market for photonic sensing, and, in a few years, will surpass the defence market. In such an environment European industry has

12 “The Leverage Effect of Photonics Technologies: the European Perspective”, Photonics21
chosen well, as it takes 30% of the whole market but only 15% of the defence sector. In the two larger segments Europe holds a revenue share higher than this 30% mean value:

- Europe’s share of the biometric market is 45% of €5 billion\(^1\)
- Europe’s share of the video surveillance camera market is 40% of €1.7 billion.

**The European Photonics industry and Photonics21**

In addition to the above-mentioned challenges, the European photonics industry is facing fierce competition from the Far East (China, Korea, Taiwan and Japan), India and the US, where substantial financial resources are being invested in photonics. The ability of the European industry to customise and provide successful end-to-end solutions, particularly photonic solutions, will be the key to securing future employment for Europe.

The photonics stakeholders are very well organised around the Photonics21 European Technology Platform (known as Photonics21) launched in 2006: the platform includes 1100 organisations with more than 2000 members, half of them come from industry. See the next section for more details.

Acting on behalf of the European photonics community over the period 2007-2013, Photonics21 has produced two industry-defined Strategic Research Agendas for Photonics in Europe. These have been instrumental in securing substantial support under the 7th Framework Programme for Research and contributed significantly to photonics being recognised as a Key Enabling Technology (KET) for Europe.

In February 2011, the European Photonics Industry presented their ‘Vision for Photonics in European’\(^13\) to Commissioner Neelie Kroes. She subsequently invited them to submit a proposal for the formation of a Photonics Public-Private Partnership, and offered to personally champion the cause of such a Photonics PPP within Horizon 2020. Photonics21 has subsequently worked closely with European Commission Photonics Unit of DG Connect to establish the Multiannual Strategic Roadmap that underpins this proposal for a photonics PPP.

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\(^{13}\) See the document ,Photonics – Our Vision for a Key Enabling Technology of Europe
Figure 4: Geographic distribution of Photonics companies and research institutes in Europe (data from Photonics21 database, representing ~50% of companies present in Europe, Source: KET sector report Photonics, 2010)
Participants in the PPP

The PPP will represent a broad constituency, involving industry (both large companies and many SMEs), research and academic actors, end-users (such as the automotive industry, EU cities and professional users such as medical doctors), and regional & national innovation clusters.

A large number of these players are represented in the Photonics21 European Technology Platform. Indeed, in 2006, the major photonics stakeholders joined forces through Photonics21 to create a common strategy and establish co-operation to spur innovation. Since then, Photonics21 has evolved to represent photonics experts from industry and research throughout Europe, and its membership has increased rapidly from the original 250 members to more than 2000, predominantly SMEs, coming from more than 1100 different organisations and including all 28 member states of the European Union (see Figures 5 & 6).

Photonics21 unites the majority of leading photonic industries and relevant R&D stakeholders and end user industries throughout Europe along the whole value chain. In addition, it also includes several photonics national technology platforms and innovation clusters from all over Europe. After seven years of operation, Photonics21 has put the photonics community in Europe on a firm footing. There is a shared belief among all members that a strong transnational cooperation between industry and academia is the only way forward if Europe is to become even more competitive in photonics.

Figure 5: Classification of the Photonics21 membership

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14 2012 membership data
The European Dimension of the PPP

Europe now needs to build further on its strong position in the global photonics markets, and it will be crucial to align and coordinate this highly multidisciplinary and fragmented field. Europe needs to strengthen its industrial leadership by promoting wide-scale cooperation and greater integration across the whole research and innovation value chain, from advanced materials to manufacturing and from advanced research to technology take-up, pilot lines and demonstration actions. A Photonics PPP is seen as the optimal vehicle for achieving this critical next development.

However, the full photonics value chain does not yet exist in many European member states, and this presents a significant barrier to the expansion of their local photonics industries. The pan-European dimension offered by collaboration within a PPP provides a means to overcome this, securing access for all participants to complementary partnerships between technology providers, manufacturers and end users.

For the first time the PPP allows a strategic implementation of a research and innovation strategy which will serve as the basis for an industrial strategy for the whole photonics sector across Europe. The Photonics PPP will steer the implementation process for achieving this strategy.

As evidenced by the membership of Photonics21, the photonics industry in Europe is largely made up of SMEs, with over 95% of photonics companies in Europe having less than 500 employees.
employees\textsuperscript{16}. SMEs provide a vibrant and responsive industry base, and are responsible for the majority of the forecast industrial expansion (70\% of the growth forecast by 2015 comes from such small to medium sized companies\textsuperscript{17}). However, to achieve this great potential, they also need special consideration and support to help them become global players. Therefore, particular emphasis will be given in the proposed Photonics PPP to supporting the innovation of the large number of SMEs active in this area.

On the political level, EU Member States have begun to coordinate their funding activities through the Photonics21 mirror group, which includes national funding agencies drawn from 15 member states and associate states (Austria, Belgium, Germany, Finland, France, Israel, Italy, Latvia, The Netherlands, Norway, Poland, Spain, Sweden, Switzerland, and the UK) and three regions (Catalonia, Flanders and Tuscany). The mirror group members have developed strong co-operation, resulting in joint funding actions, such as three ‘ERANET+’ actions, for more than € 55 million of EU and national funding. This activity is seen as start for a further tighter coordination of member state and European activity.

By including the regional clusters in the PPP, for the first time Europe will have a comprehensive vertical industrial strategy which includes the European, national and regional players.

**Added Value of the PPP**

The proposed Photonics PPP will differ from the existing support mechanisms by establishing a closer alignment of industrial and public (regional, national, and European) strategies, and by pooling academic, industrial and public resources to provide sufficient know-how and the investment that will be essential for achieving major progress towards this joint strategy.

The Photonics PPP will:

- Increase the production volume, the revenue growth and potentially the market share for the European photonics industry.
- Bring together the different national champions in a strategic manner acting in different parts of the value chains and enable innovation at EU level along and across the whole value chain and in related business ecosystems.
- Accelerate the innovation cycle and the translation of knowledge into innovative products and services, thus securing the EU's global leadership in photonics and in markets leveraged by photonics.
- Allow end user industries in Europe to become more competitive by deploying the key enabling technology photonics in their production process (e.g. lasers in automotive, aviation and medical technology industry) or products.
- Act as catalyser for enhancing synergies between EU-photonics programmes, and national and regional photonics strategies (Smart Specialisation).
- Monitor the photonics roadmap implementation and therewith take a strategic approach to a more competitive photonics industry sector in Europe.

No individual industry sector or European country has the required multi-disciplinary capability to act at such level and scale of excellence in photonics.

\textsuperscript{16} EPIC/TEMATYS Report ‘Photonics Ecosystem in Europe’, April 2013

\textsuperscript{17} EPIC/TEMATYS Report ‘Photonics Ecosystem in Europe’, April 2013
Long Term Vision for the PPP

The Photonics PPP will provide the cornerstone for EU industrial leadership in photonics, in particular in those application areas where photonics is driving innovation and Europe is particularly strong (for example, lighting, medical photonics, and optical components & systems), or where there is potential for creating new markets; and, contribute to the creation of a highly skilled workforce and the capability to generate new jobs that attract young people.

Through the long-term commitment of all parties to a common shared vision, the proposed Photonics PPP will provide the basis for a Research and Innovation strategy and more broadly for an industrial strategy for photonics in Europe for the next 7 years that will lead to a more competitive photonics sector in Europe. Embracing the main recommendations of the KETs initiative (and the main findings of the SWOT analysis presented above), the Photonics PPP will be vital for achieving the critical mass necessary for developing a coherent application oriented and market needs driven technology & innovation for strengthening RDI capabilities across the full value chain, from research to manufacturing and from materials to OEMs & end users. It will develop and implement an integrated RDI programme that fully meets the needs and priorities of markets, and tackles the ‘valley of death’ problem by undertaking strategic projects. Continued close collaboration with member states\(^\text{18}\) will be critical for the success of this PPP.

Objectives of the PPP

The overall objectives of the proposed Photonics PPP are to:

- Foster photonics manufacturing, job and wealth creation in Europe through a long term investment commitment by both industry and the European Commission;
- Accelerate Europe’s innovation process and time to market by addressing the full innovation and value chain in a number of market sectors where European photonics industry is particularly strong (e.g. lighting, medical photonics, and optical components & systems);
- Mobilise, pool and leverage public and private resources to provide successful solutions for some of the major societal challenges facing Europe, in particular in healthcare & well-being, and energy efficiency.

This will be achieved through a number of specific objectives:

Objectives for Improved Competitiveness

- Increase the production volume and revenue growth, as well as maintain or even increase to more than 18 % the world market share of the European photonics industry (Reference: Europe’s 2012 position was at 18 % of total production);
- Increase the uptake of photonics based technologies by end-user companies, in particular SMEs, where this can provide a competitive edge to their products;
- Stimulate existing and new alliances and business ecosystems along and across the value chain that reinforce competitive capabilities of the European photonics industry in existing market segments or help address new market segments;
- Increase the competitiveness of SMEs by providing EU-wide access to photonics technology, experimentation and manufacturing capabilities.

\(^\text{18}\) Through the Photonics21 Mirror Group
Objectives for Innovation

- Address the "valley of death" (i.e., the transition from advanced research prototypes to marketable products) by accelerating the wide diffusion of photonics technologies in many industry sectors and the emergence of new business ecosystems;
- Develop additional capabilities in new product segments, new manufacturing capabilities, new applications, and new technology areas;
- Make the innovation process more inclusive, sustainable and effective through the direct involvement of players along and across the full value chain.

Objectives for Socio-Economic Benefits

- By 2020, increase at least by 10 % the number of high skill jobs in the photonics industry and through leverage in other industry sectors [Reference: there were more than 300,000 direct jobs in the photonics industry in 2012];
- Increase training and education opportunities for securing a skilled workforce.

Underpinning all the proposed activities are the objective of growing photonics manufacturing in Europe and creating further ‘high skill’ employment. This will be achieved by enabling the photonics products themselves to be manufactured in Europe, and by ensuring the on-going competitiveness of other key photonics-dependent manufacturing sectors in Europe.

The implementation of the Photonics Multiannual Strategic Roadmap, which has been widely endorsed by the photonics community in Europe, will be the key objective for a Photonics PPP in Horizon 2020. The roadmap highlights the need for Europe to strengthen its ability to make the critical transition from successful innovation in photonics to the industrial deployments necessary for job creation. Bridging this gap must be a key objective of the Photonics PPP. For photonics to yield its full potential as an enabling technology, it will be critical that the inherent synergies within the sector are exploited through integrated research aimed towards identified market solutions, rather than towards isolated components or applications.

Finally, in the roadmap it is stressed that disruptive photonics research is of major importance for maintaining the long-term competitiveness of the European photonics industry. Therefore, photonics disruptive research will play a significant role within the PPP.

To this end the PPP will largely support EU 2020 targets, namely to create jobs (Target: 75 % of the 20-64 years olds to be employed), increase investment in R&D (Target: 3 % of the EU’s GDP to be invested in R&D). Moreover the PPP will provide solutions (e.g. through green photonics: energy efficient lighting, optical communication networks, etc.) to address climate change and energy sustainability (target: 20 % increase in energy efficiency) and foster high skilled education (target: at least 40 % of 30-34–year-olds completing third level education).
Part II: Research and Innovation strategy

Introduction

The dual challenge facing Europe is both to lead in photonics technology innovation, and to exploit these results through successful commercialisation. In this way, the goals of solving the grand societal challenges and of generating sustainable economic growth in Europe can be met. By implementing this strategy, the 21st century will truly become the century of the photon.

The potential Research and Innovation activities best placed to address these challenges and objectives are:

- **Road-map based and disruptive and core photonic technologies**
  
  Two approaches will be taken to developing core technologies:
  
  - Roadmap-based research will be undertaken to drive technological development and innovation in strategic application areas where Europe is strong. These strategic application areas include optical data communications, laser manufacturing, biophotonics for medical and biomedical applications, imaging and sensing for safety, security and the environment, and visualisation and lighting. The emphasis will be on broader cooperation across the whole research and innovation value chain and the close involvement of end-users, including citizen groups where appropriate.
  
  - Disruptive technology breakthrough advances in nanophotonics, quantum optics and quantum information, extreme light sources, etc. will be pursued, complementing the roadmap-based research and bringing the potential for disruptive innovation in support of future European leadership.

- **Demonstration**
  
  Specific deployment programmes using photonic innovations will be needed to demonstrate social innovation and leverage EU infrastructure to create jobs. Such infrastructural projects could provide benefits to all 550 million people in the EU, and not solely to those directly involved in the photonics industry. Deployment programmes would in particular focus on lighting, life cycle, and applications.

  In this way, coordinated market pull/push measures will seed and then accelerate market penetration, ultimately leading to wider technology adoption and consequent job creation. Measures would include the launch of high-visibility, demonstration projects that provide the European photonics industry with a first-mover advantage in the global market.

- **Photonics Manufacturing Platforms & Pilot Lines**
  
  Underpinning all the proposed activities is the objective of growing photonics manufacturing in Europe and creating further high skill employment. This will be achieved at two levels; enabling the photonics products themselves to be manufactured in Europe, and ensuring that other key manufacturing sectors in Europe, dependant on photonics technology, can remain competitive. To this end the following measures would be implemented:

  - Improvement of the infrastructure for photonics manufacturing in Europe. This involves making full use of the existing manufacturing excellence of research institutes for supporting industry, especially innovative SME’s. Creation of such generic, open-access photonic foundries will enable cost-effective and widespread deployment of photonics technology in numerous applications, and ultimately lead to high volume production.
Establishment of pilot production facilities, in which industry and research institutes can jointly develop innovative photonics production processes, targeting applications relevant to societal challenges and economic growth. Since the value chains in specific photonics application areas in Europe are often fragmented across different member states, demonstration activities and manufacturing platforms are expected to re-enforce the innovation ecosystems at local/regional (smart specialisation) and European level.

- **Innovative SMEs**

  SMEs lie at the very heart of the European photonics industry, and play a major role in driving innovation and economic growth. It is essential for the future prosperity of the European industry, and thereby of European society, that their competitiveness in the global market is sustained and grown further. The following actions will be undertaken to support SMEs:

  - Provide access to feasibility, testing, prototyping and manufacturing capabilities for photonics research-intensive and end-user SMEs, though dedicated schemes designed to be fast and administratively light.
  - Ensure involvement in R&D activities, both as part of the value chain collaboration and through specific actions aimed at SMEs. In particular, open innovation models along the value chain will further promote the collaboration between large industry and SMEs. To this end, the SME (both as end-users and supplier SMEs) activities will be mainstreamed within the overall strategy implementation.
  - Establish open-access pilot line and foundry services to provide SME access to photonics manufacturing capabilities

Further synergies with regional innovation clusters will be established to promote SME development through, for example, the establishment of open innovation models along the value chain. This would allow SMEs to operate within a streamlined, more market-oriented set of rules, allowing support for prototype development leading to shorter-term commercialization.

- **Strengthening Photonics Foundations**

  The actions of the Photonics PPP will be accompanied by measures on education, training and skills development. Both industry and academic partners of the PPP will undertake these actions to secure the future work force for this growing industry. Additional actions that will be launched include standardization and targeted international cooperation.

All activities will be accompanied by measures to better attract sufficient capital and management support for seeding and growing innovative business ideas. The PPP will work towards the establishment of a dedicated European industrial growth fund, leveraging existing investments in photonics innovation through to commercialization.

In preparation for a Photonics PPP within the new Framework Programme Horizon 2020, the European photonics community coordinated by Photonics21 has prepared a detailed Photonics Multiannual Strategic Research and Innovation Roadmap. Throughout the whole roadmapping process, the photonics community and the Photonics21 Work Group Chairs have engaged in a close dialogue with the European Commission Photonics Unit of DG Connect.

The Photonics Multiannual Strategic Roadmap was the result of extensive brainstorming and discussions with more than 400 experts from the European photonics community. They have
identified strategically important photonics research and innovation challenges as well as cross-cutting Key Enabling Technology issues, and have outlined the need for Europe to invest further in these identified application areas and photonics technologies.

The roadmap describes the RDI challenges facing Europe’s photonics community, outlining the specific research and innovation areas envisaged by the seven Photonics21 Work Groups within the framework of the Photonics PPP. Each Work Group has defined relevant research and innovation areas, and has also produced a series of roadmap tables for the full planned duration of Horizon 2020, covering the period 2014 – 2020.

The complete Photonics Multiannual Roadmap is provided in Appendix A.

**Key Stakeholders**

Participants in the photonics PPP will include stakeholders from across the full value chain for European photonics, ranging from researchers through to end-user industries. As illustrated in Figures 4 and 6, the Photonics21 already includes a large proportion of the European photonics community, and this will be extended to ensure that the PPP participants are truly representative.

Through Photonics21 itself, the participation of the majority of the leading photonics industrial players is assured, ranging from the largest companies such as OSRAM or Alcatel-Lucent, to the many thousands of photonics SMEs active in this technology, and through them an extensive range of end-user contacts. Its membership includes all the major photonics research institutes and academic groups in Europe, and a large number of end-users.

A broad range of multidisciplinary participants will be involved in the PPP activities, as this is usefully illustrated by the following two example applications:

**Solid State Lighting** - the full value chain is represented, running from the research institutes developing new materials and device concepts, to LED and microelectronics manufacturers, to the luminaire suppliers, to system installers, to the intermediary lighting architects, right through to the end users, such as commercial outlets, hotel chains, and municipal cities.

**Medical Equipment Technology** - the full value chain is represented, running from the University groups researching biophotonic interactions leading to new therapies, to component manufacturers providing the necessary lasers and detectors, to medical equipment manufacturers doing the integration, to teaching hospitals providing the clinical trials, right through to medical doctors and clinicians providing treatment to patients.

On the public side of the PPP, there is the European Commission (mainly represented through the Photonics Unit of DG Connect). In addition, many Member States will be participating through the Photonics21 mirror group membership that coordinates the interests of EU Member States. Additionally, Photonics21 has established direct links with all the major national technology platforms and regional innovation clusters and national technology platforms, as illustrated in Figure 7.
Figure 7: European photonics regional innovation clusters and national technology platforms.

Strategic Roadmap Overview

The Photonics Multiannual Strategic Roadmap was jointly developed and adopted by the members of the European Technology Platform Photonics21. The photonics roadmapping process was launched at the Photonics21 Annual Meeting in March 2012. The first draft was made available at the end November 2012 and was highly publicised and promoted by Photonics21 and the European Commission's photonics Unit. The open consultation ended mid-February 2013 and resulted in the publication of the roadmap in April 2013.

The roadmap embodies the plans for photonics research and innovation in each of the different photonics application fields addressed by Photonics21:

- Information & Communication
- Industrial Manufacturing & Quality
- Life Sciences & Health
- Emerging Lighting, Electronics & Displays
- Security, Metrology & Sensors
- Design & Manufacturing of Components & Systems
- Research, Education & Training
The topics and research areas addressed in the photonics roadmap have been selected and discussed by more than 400 photonics experts that attended the fourteen separate Photonics21 workshops held during 2012. This process ensured a comprehensive consultation of the European photonics community, and resulted in a democratically agreed seven-year technology and innovation plan.

The Photonics Multiannual Roadmap document is presented in Appendix 1. The following table summarises the overall plan presenting an overview illustrating selected technology highlights. Detailed plans are presented individually in the full roadmap for each technology application field.

Clearly, the full cost of completing all the sector roadmaps in their entirety would be well in excess of the likely funding available. Therefore, a critical role for the PPP will be to prioritise the immediate aims of the partnership to best balance the short-term prospects for commercial exploitation and solution of societal challenges, against the longer-term requirements for establishing new photonics technologies that will ensure future product opportunities. These requirements will evolve throughout the lifetime of the PPP and the detailed implementation will need to reflect the changing status of technologies and end user requirements. A two-year cycle of technology review and RDI priority setting will be adopted to achieve this. The private and public partners of the PPP will perform this task jointly, with the primary outcome being the definition of the Horizon 2020 workplan and its implementation through the specific content of the periodic calls for proposals.
<table>
<thead>
<tr>
<th><strong>Information &amp; Communication</strong></th>
<th><strong>2014/2015</strong></th>
<th><strong>2016/2017</strong></th>
<th><strong>2018/2019</strong></th>
<th><strong>2020</strong></th>
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<tbody>
<tr>
<td>Concepts for system architectures to deliver up to 1 Tbps per channel and up to 1 Pbps per fibre in the core/metro network</td>
<td>Tbps components based on Silicon/InP</td>
<td>Development of integrated solutions for optical interconnection concepts</td>
<td>System design, integration and verification for selected high-impact applications</td>
<td>Deployment in European National Research and Education Networks</td>
</tr>
<tr>
<td><strong>Industrial Manufacturing &amp; Quality</strong></td>
<td>Improved efficiency lasers and processing systems</td>
<td>Diffraction limited fibre delivery (&gt;1 kW, &gt;100 m)</td>
<td>Fibre transport of ultra-short pulses</td>
<td>Highly individualised products in mass markets (transportation, medical, consumer)</td>
</tr>
<tr>
<td>Enhanced process monitoring sensors</td>
<td>Multispectral imaging sensors implemented</td>
<td>UV direct imaging for high resolution processing</td>
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<tr>
<td><strong>Life Science &amp; Health</strong></td>
<td>Development of reliable low-cost photonic-based screening methods for fast risk assessment of age and life-style related diseases</td>
<td>Improved analytic photonic methods to allow more reliable and precise further analysis of positively screened persons</td>
<td>Improved, safer and personalised treatment based on multi-band photonic techniques and methods or on combinations of photonic and non-photonic modalities</td>
<td>Next generation analytical, low-cost and fast methods to control water and food safety/quality</td>
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<td></td>
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<td>Photonics-based highly targeted therapies and continuous monitoring of therapeutic success</td>
</tr>
<tr>
<td><strong>Emerging Lighting, Electronics &amp; Displays</strong></td>
<td>Cost-performance breakthroughs for OLED and OPV manufacture</td>
<td>Roll out of intelligent lighting for cities</td>
<td>Adaptable open-access production facility for flexible electronics</td>
<td>Open system architectures established for OLEDs</td>
</tr>
<tr>
<td>Heterogeneous flexible electronics system on a foil for mass-production</td>
<td>High-speed production facility for flexible OLEDs</td>
<td>Integration of OPV into building components &amp; pilot installations established</td>
<td></td>
<td>3D glasses-free multi-view and near-to-eye displays demonstrated</td>
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<td>Display systems for ultra-high performance viewing</td>
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</tr>
<tr>
<td>Security, Metrology &amp; Sensors</td>
<td>New materials and principles for extended-IR lasers, LEDs, 1D/2D detectors, and passive optical devices Buildup of European network of competence in extended-IR devices and systems</td>
<td>Characterisation and optimisation of device structures and performance Drive towards compatibility with micro-electronics production facilities</td>
<td>Buildup of cost-effective production capacity using modified micro/nano-electronics fabrication facilities Demonstration actions for all selected showcase examples</td>
<td>International market penetration with new low-cost extended-IR systems, components &amp; applications Joint field tests with end users. Buildup of user communities, producing and exchanging databases and practical experiences</td>
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<tr>
<td>Design and Manufacturing of Optical Components and Systems</td>
<td>Develop processes &amp; building blocks for second generation photonic integration platforms, maximizing energy efficiency, high density and functionality New concepts for economic packaging &amp; assembly of high performance, high functionality PICs</td>
<td>Demonstrate viability of second-generation generic platforms through the proving of application-specific designs Establish pilot for next-generation assembly of high volume, high precision discrete devices and PICs</td>
<td>Nanophotonic devices, scalability to very high complexity circuits, maximum energy efficiency Initiate research into capability enhancements, including compatibility with forthcoming ITRS CMOS nodes</td>
<td>Proving of device technologies through candidate applications Introduce pilot lines for second-generation electronic/photonic platforms</td>
</tr>
<tr>
<td>Disruptive Research</td>
<td>Explore new nano-engineered materials Explore potential of light-matter interaction in new extreme regimes Involve photonics-based and photonics-enabled industries to define their long-term needs</td>
<td>Realise and characterise quantum-based simple integrated circuits as building blocks of future quantum devices and systems Define areas of major market potential</td>
<td>Exploit light-matter interaction in new regimes for material processing, material characterisation, and device fabrication Guarantee open access to infrastructures for both academic institutions, research centers and SMEs</td>
<td>Realisation of engineered prototypes based on nanophotonics providing new characteristics and functionalities Involve all industrial players and end-users to bring innovation to production and market exploitation</td>
</tr>
</tbody>
</table>
| **Education & Training** | Address school students with specific programs, starting from existing experience  
Promote photonics through different media: press, TV, internet, apps, conferences related to art events, etc | Organise courses mainly targeting SME needs on a local basis  
Involve industries for sponsorship of outreach programs and of team competitions on specific problems | Ensure stability and self-sustainability of best initiatives  
Strengthen cooperation with industries | Reach a pan-European dimension for most successful outreach programs, and create suitable structures to ensure maintenance |

Figure 8: Photonics PPP Roadmaps - selected technology highlights by sector
Part III: Expected Impacts

Industry Commitments
The commitment of the stakeholders within the European photonics community is clear. Through Photonics21 they have jointly developed an extensive technology roadmap, and they are now committed to implementing it. As part of their engagement in doing so, more than 60 companies and institutions have already signed up to this roadmap and its commitments (see last page of Annex 1), and many more are expected to sign it in the coming months.

- In recognition of the importance of forming a PPP, the European Photonics Industry undertakes to make a substantial financial commitment through a four-fold leverage of public funding to achieve a total investment of €7 billion (€5.6 billion from the private sector and €1.4 billion from the European Commission) over the period of Horizon 2020. This would also result in a substantial increase of employment in the photonics industry, many being highly skilled employees and further leverage to additional jobs for the European industry overall.

Broader additional commitments from industry but also from other stakeholders such as academia and research institutes include:

- Commitment to providing solutions that address the major societal challenges;
- Commitment to work closely with SMEs;
- Commitment to skills creation and to improving education curricula;
- Commitment to wide promotion and dissemination activities.

The success of the PPP will depend critically on the degree of engagement achieved with all stakeholders, both from within the photonics community itself, and more widely with the potential end users in other industry sectors that rely on photonics technologies. The European Photonics Industry recognizes that this engagement, most critically the engagement with end users, will drive a new wave of innovation and will significantly increase the take-up of photonics technologies within the European industry. This commitment to stronger end user engagement is embodied in each of the photonics sector roadmaps. In this way, a Photonics PPP will greatly enhance the overall innovation environment within Europe, resulting in a faster time to market for new products and applications.

Expected Impacts

Impacts on Industrial Competitiveness and Economy

- An improved and more competitive production capability leading to increased production volume of the European photonics industry itself and the European end user industries;
- Development of new business ecosystems through strong and sustainable alliances along and across the value chain that:
  - increase the innovation capacity of the photonics industry and strengthen its competitive position in existing or new market segments,
  - create new business/market opportunities in particular for SMEs helping them to grow and internationalise,
  - contribute to the creation of new SMEs
Higher levels of private and public investments leading to strengthened competitiveness of European Regions by coordinated application of industry funds, Horizon2020 funds, structural funds, the funds from the European Investment Bank and Venture Capitalists.

**Impacts on Innovation**
- Accelerating Europe’s innovation process and time to market by addressing the full innovation chain in a number of market sectors where European photonics industry is particularly strong (e.g. lighting, production technology, medical photonics, and optical components & systems);
- Integrating the full value chain by also considering an open innovation approach, thereby mitigating the "valley of death" problem;
- Accelerating the diffusion of innovative photonics technologies in many industry sectors and application areas;
- Providing an enabling technology to develop – jointly with European professional users and end user industries – additional functionalities and capabilities leading to the development of new market-valued product segments and applications and/or new manufacturing capabilities.

**Socio-Economic Impact**
- Grow photonics manufacturing in Europe thereby creating ‘high skill’ employment. This will be achieved by enabling the photonics products themselves to be manufactured in Europe, and by ensuring the on-going competitiveness of other key photonics-dependent manufacturing sectors in Europe;
- Addressing the skills gap, attracting young people in photonics and providing new training and education opportunities;
- More effective and very wide dissemination and outreach through increased publication of articles or other dedicated audio-visual/multimedia material, participation in major European trade shows, and increased activity using social media;
- Addressing key societal challenges in Europe, such as:
  - 70 % energy savings of cities could be reached through the wide deployment of intelligent Solid State lighting systems.
  - Low cost screening for the very early detection of major health diseases (e.g. cancer, cardiac) and advanced treatment have the potential of leading to 20 % cost savings.
  - Reduced cost of sensing of environmental pollution or contamination, good quality food (raw food or packaged goods) and water (drinking and wastewater), are possible by using affordable solid state Infra-Red sources.

**Leveraging R&D**

As previously mentioned, the European Photonics Industry undertakes to make a substantial commitment in the photonics PPP, through a four-fold leverage of public funding to achieve a total investment of € 7 billion (€ 5.6 billion from the private sector and € 1.4 billion from the European Commission) over a period of 7 years (2014-2020).

Therefore, the European photonics industry is committed to a four-fold leverage of public investments. It is also engaged to support SMEs and young workers through the creation of new jobs and skills. The photonics industry has the capacity to proceed to this level of investment. Recent studies show that in the last 5 years, this industry is investing between 5% and 10 % of...
its annual turnover on RDI activities. The PPP will significantly boost such further RDI and manufacturing investments.

The creation of a PPP of this scale would in addition permit the photonics industry to be able to negotiate loans and equity funds from the EIB and/or the EIF and to include photonics R&I actions in the new Regional Cohesion policy, under the smart specialisation strategies of the regions. Such funds are essential to complement the Horizon 2020 funds needed for the creation of multi-million € pilot photonics manufacturing lines and the launch of large scale pilot demonstrators essential for the validation of photonics solutions in real settings.

In addition to the above, it is expected that further leveraging will be achieved through the PPP’s involvement of the full value chain in defining strategic direction, resulting in increased end user awareness of the capabilities of photonics technology and better access to the new design tools and processes based on them. This in turn will lead to the identification of new potential application areas and methodologies, and so provide opportunities for additional investments towards new RDI directions and priorities.

Photons as a key enabling technology will leverage RDI and Manufacturing in European high volume application industries, as new tools are developed jointly with end-user industries, and will improve the competitiveness of important industry sectors for Europe.

Three concrete examples of demonstrated industrial leverage include:

**Automotive and Aviation Industries**
Photonics will allow European carmakers and the aviation industry to use composite material for lightweight structures. This allows reduced fuel consumption, while at the same time increasing safety, representing a significant competitive advantage.

**Medical Technology Industry**
Photonics based techniques allow fast and accurate detection of indicators of disease, such as disease molecular biomarkers or disease dependent optical properties of cells. Such photonics based solutions have the potential to detect and diagnose disease much more rapidly and at an earlier stage of disease development than conventional techniques. This enables a more effective and less heavy intervention, meaning greater survivability and lower cost. Photonics based diagnostics will provide a competitive advantage to the medical equipment industry in Europe (in particular for mobile point-of-care diagnostics).

**Food and Manufacturing industry**
Improved photonic sensors will find ever-wider applications for process control and quality monitoring in the food processing and manufacturing industries. The use of new wavelength ranges, optimised optical systems, and sophisticated signal processing algorithms will dramatically improve the range of things that can be sensed and the achievable sensitivities.

**Coordination of the PPP**
In close cooperation with the European Commission, all the PPP projects will be monitored regularly against their own objectives and more broadly, against the targets defined in the Photonics Multiannual Strategic Roadmap. This process commences at the point when calls are
defined to ensure they include information on the required roadmap-compatible target outcomes (technical specifications and other measurable outcome indicators).

More specifically, a number of indicators will be monitored per project that will provide a broader perspective, i.e., a map that will be created and maintained for each application area and horizontal domain of the Photonics PPP, showing the status of current project achievements against the workplan defined targets. This will include the coverage of the value chain (essential involvement of end-user industries and supply chain partners as well as of SMEs). If judged necessary, corrective actions will be implemented to influence the on-going direction and scope of future calls of the Photonic PPP.

The specific Work Groups of Photonics21 covering the European experts in the field - in conjunction with the DG Connect Photonics Unit - would provide a possible well-coordinated vehicle for monitoring achievements of the PPP project.

**Key Performance Indicators**

In order to control the bold commitment of the European Photonics industry, but also the functioning of the PPP itself a set of Key Performance Indicators have been determined.

**Overview**

**Indicators for Impact on the Industrial Competitiveness and Economy**

- Four-fold leverage of public funding by Industry
  
  A fundamental characteristic of the PPP, and the one that clearly differentiates a PPP from previous support mechanisms, is the firm long-term commitment from Industry. In recognition of the importance of forming a PPP, the European Photonics Industry undertakes to make a substantial financial commitment through a four-fold leverage of public funding to achieve a total investment of € 7 billion (€ 5.6 billion from the private sector and € 1.4 billion from the European Commission) over the period of Horizon 2020. This will constitute the primary Key Performance Indicator for the PPP. This commitment is based on the aggregate performance of the photonics industry partners, and not necessarily on an individual company basis. In this context, ‘downstream industry investment’ is defined as research/innovation related investment in Europe\(^\text{19}\).

  An additional indicator for Industrial Competitiveness and Economy is to maintain or even increase the market share of the European photonics industry of the global photonics market by 2020. The baseline 2012 for the European Photonics market share is ~18 %

**Indicators for the Socio-Economic Impacts**

- Number of people directly employed by the photonics industry will be increased by at least 10 % through the creation of new jobs against the 2012 baseline of 300 000 direct jobs. The demonstrated leverage effect of photonics is expected to result in substantial new employment opportunities in other sectors, but this is not readily quantified, and unsuitable for a performance indicator.

\(^{19}\) Such broader KPI is necessary given the objective to position the PPP at the centre of a European R&I strategy, where many companies may benefit from the creation of the PPP beyond those who will be direct beneficiaries of Horizon 2020 grants. This includes for example companies getting access to EIB loans or regional funds, benefiting from participation in ERANET initiatives, getting access to EU-wide access services to technological and manufacturing capabilities, etc.
Highlighted success stories relating to key developments in photonics, such as major technology breakthroughs (in terms of unprecedented functionality or performance of a prototype system/device), engagement with new industrial sectors or markets, and the identification of breakthrough solutions for specific societal challenges.

Education, training and skills developments. Suitable metrics are the number of specific activities undertaken to attract young minds to photonics or the number of young students addressed by educational material on photonics.

Indicators covering the operational aspects of the PPP
A variety of metrics will be adopted for monitoring the PPP operation. Some of these would be monitored by the PPP itself, whilst others could be monitored through the planned KET observatory implemented by DG Enterprise.

Efficiency, openness and transparency of the PPP Consultation Process
The Photonics PPP must strive to reflect accurately the views of the whole of the European photonics community, and this can only be achieved by ensuring that consultation is broad and that decisions are achieved in a democratic manner.

- Monitoring the number and profile of participants contributing to the strategy and implementation workshops;
- Monitoring the profile of Photonics21 members and the Board of Stakeholders members to provide indicators of a representative and broad consultation process;
- Monitoring of the decision making process during the consultation.

The European Commission will be invited to monitor each individual step in the process.

Indicators for the PPP Project Performance
The following indicators will be used to monitor progress of the PPP implementation of its RDI strategy:

- Time to contract;
- Levels of response to calls;
- Progress against technology roadmap timetable;
- Value chain correctness of PPP projects;
- Participation of Industry & SMEs in PPP projects. Target: Increase industry participation to 50 % in terms of both participants and funding over the 2012 baseline of approximately 36 % (in terms of participants) and 35 % (in terms of funding). SMEs should account for 50 % of industry participation.

Key Performance Indicators in detail:

A. Indicators for Impact on the Industrial Competitiveness and Economy

• **KPI 1: Maintain / Increase the (European) market share of the global photonics market**
  **Baseline:** In 2012, the global market share of Europe was 18%  
  **Target:** By 2020, keep a global market share of at least 18%

• **KPI 2: (Develop) New photonics R&I capabilities for addressing the valley of death**
  **Metrics:** new pilot lines and manufacturing capabilities and involvement of stakeholders
• **KPI 3: (Improve) the innovation potential of photonics companies and notably of SMEs**  
**Metrics:** new open access infrastructures and services to design, prototyping, manufacturing or testing, etc., and involvement of SME stakeholders;

B. Indicators for the socio-economic Impacts

• **KPI 4: Number of people directly employed by the photonics industry**  
**Baseline:** In 2012, there were 300 000 direct jobs  
**Target:** by 2020, increase by at least 10% new jobs in photonics

• **KPI 5: Education, training and skills development**  
**Metrics:** number of specific activities undertaken to attract young minds to photonics or the number of young students addressed by educational material on photonics

• **KPI 6: Scale of diffusion of photonics in application areas and in solutions addressing societal challenges**  
**Metrics:** Representative examples of photonics in application areas and of breakthrough solutions for specific societal challenges

C. Indicators covering the operational aspects of the PPP

• **KPI 7: R&I investments of the photonics industry in the PPP objectives:**  
**Metrics:** Volume of investments on photonics R&I including:  
  a. investments of companies participating in H2020 funded projects (esp. the ones closer to the market)  
  b. overall R&I investments of the photonics industry (as described in the proposal).  
**Target:** A four-fold leverage of the public funding that the photonics PPP will receive during the 7 years of Horizon 2020

• **KPI 8: Efficiency, openness and transparency of the PPP Consultation Process**  
**Metrics:**  
  – Monitoring the number of participants contributing to the strategy and implementation workshops  
  – Analysis of Photonics21 members and the Board of Stakeholders members to provide evidence for representation of the Photonics community  
  – Monitoring of the decision making process during the consultation

• **KPI 9: The PPP Project Performance**  
**Metrics** to monitor progress of the PPP implementation and of its RDI strategy:  
  – Time to contract  
  – Levels of response to calls  
  – Progress against technology roadmap timetable  
  – Value chain correctness of PPP projects  
  – Participation of Industry & SMEs in PPP projects. Target: Increase industry participation to 50 % in terms of both participants and funding over the 2012 baseline
of approximately 36% (in terms of participants) and 35% (in terms of funding). SMEs should account for 50% of industry participation.

- **KPI 10: Success stories relating to key developments in photonics by H2020 funded projects**
  - **Metrics:**
    a. technology breakthroughs (in terms of unprecedented functionality or performance of a prototype system/device), engagement with new industrial sectors or markets, and the identification of breakthrough solutions for specific societal challenges
    b. Patents and contributions to standards (where appropriate) by H2020 funded projects

- **KPI 11: Coordination of the PPP implementation with the Member States and the Regions**
  a. Strategy implementation coordinated and combined with regional and national activities in the field;
  b. R&I cooperation activities launched with national and regional funding agencies
  - **Metrics:** Number of cooperation meetings with national technology platforms and innovation clusters, mirror group meetings; examples of cross-national and cross-regional cooperation actions; number of new ERANETs launched, etc.

- **KPI 12: Dissemination and Awareness**
  - Make Photonics visible to the general public in Europe and to a broad range of stakeholders
  - **Metrics:** wide dissemination of information and tangible examples about how Photonics solutions contribute to the day to day live of European citizens by using various communication channels like social media, print, video, etc. awareness and information actions held for promoting the PPP activities to a broad range of stakeholders (within and beyond the ones included in Photonics21) – this includes events, targeted Newsletters, social media, etc.

**Monitoring Industrial Commitments**

As their primary Key Performance Indicator, sampled companies would provide one overall figure, summarising their own company’s investments in the photonics area.

The industry commitment is based on the aggregate performance of the photonics industry partners, not on an individual company basis. In this context, industry investment is defined as investment in Europe in the field of photonics research, innovation and manufacturing.

Industry investment will cover:
- R&D, design and product development;
- Pilot production and demonstration;
- Manufacturing.

This definition of the Photonics industry PPP investment can be associated with the specific Technology/ Manufacturing Readiness Levels TRL 1 - 9 and MRL 1 - 10.20

20 How Technology Gets From Concept to Fielding (Michael T. Brundage, modified by the Photonics21 secretariat)
It is understood that all contractual PPPs are asked to make a significant commitment to invest in Europe and a unified methodology and data analysis (including market analysis, analysis of European market share, job creation) will be applied to all KET PPPs. It is proposed that this becomes a directed activity of an independent actor like the planned KET Observatory Mechanism (or the JRC).

**Which investment categories should be monitored?**

The following investment categories and Key Performance Indicators in the photonics sector fall within the scope of ‘investment’ (*TRL 1-9 / MRL 1-10*) in Europe:

- **Tangible assets** (land, buildings, equipment, etc.)
- **Spending on human resources**
- **Operational spending** (e.g. pilots, demonstrations, manufacturing, etc.)

Investments in intangible assets, such as licensing and patent acquisition, are also regarded as investment provided that the exploitation takes place within Europe.

Each participating company will provide an overall figure summarizing the investments mentioned above. The form of the request will be such that it does not result in a significant additional administrative burden for the companies concerned. It is acknowledged that informed estimates, rather than auditable quantitative information, may be appropriate for some metrics.

Data supplied by the companies would be supplemented by the results of the accompanying macro-economic study on the impact of the PPP. This study should be ongoing throughout Horizon 2020 (see below) and would cover such aspects as job creation, training and skills development, dissemination, impact on societal challenges and development of SMEs. Participating companies would be required to cooperate with the study and provide, in
confidence, relevant information (where necessary, in the form of estimates) to the organization conducting the study.

The Horizon 2020 Photonics PPP will also fund innovation related projects that go beyond research and may cover demonstration and pilot production activities (TRL 5 to 8). In the latter case, companies may be asked to provide stronger commitments and to present concrete business and investment plans for subsequent deployment in Europe.

Under all circumstances it needs to be guaranteed that information provided by the companies will be handled confidentially and will only be published by the EC in an aggregated way (e.g. as total sector investment).

The monitored investments relate to the sector where PPP projects are conducted and will not be linked to a specific Horizon 2020 PPP project. It is recognized that only some projects will yield results that permit further investment and exploitation and this is taken into account in the definition of the fourfold overall investment commitment.

Monitoring of operational PPP indicators of the Photonics PPP will be done jointly by the European Commission and the Photonics21 PPP Association.

The frequency of monitoring KPIs will depend on the availability of the particular data required, but would be done at least 2 or 3 times: at the Horizon 2020 mid-term assessment (2015 or 2016) and again at least once after its completion (+2 years) for investment and market performance related data.
Part IV: Governance

Evolution of the European Technology Platform Photonics21 since its establishment

Photonics21 has been established in 2005 as an interest group of the Photonics stakeholders in Europe. The ETP Photonics21 is not a legal entity. Since its inception the ETP Photonics21 received significant recognition from both, the Photonics community in Europe and at political level. Membership in Photonics21 is nearly equally divided between industry and research and grew from 250 members in 2005 to more than 2000 members in 2013 - see Figure 10 below. The European Technology Platform Photonics21 through its 2000 members is representing 1100 photonics and end-user organisations (~50% industry).

![Figure 10: Photonics21 Membership Evolution (2005-2013)]
**Photonics21 strategy development**

Since 2005 Photonics21 – in close cooperation with the European Commission - has published a series of strategy documents to foster the competitiveness of the photonics industry in Europe:

<table>
<thead>
<tr>
<th>Strategic Research and Innovation agendas published by Photonics21</th>
</tr>
</thead>
<tbody>
<tr>
<td>1\textsuperscript{st} Strategic Research Agenda:</td>
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<tr>
<td>“Towards a Bright Future for Europe”, 2006</td>
</tr>
<tr>
<td>2\textsuperscript{nd} Strategic Research Agenda,</td>
</tr>
<tr>
<td>“Lighting the way ahead”, 2010</td>
</tr>
<tr>
<td>Vision document towards Horizon2020</td>
</tr>
<tr>
<td>“Photonics - Our vision for a Key Enabling Technology in Europe”, 2011</td>
</tr>
<tr>
<td>3\textsuperscript{rd} Strategic Research and Innovation Agenda (PPP Multiannual Roadmap)</td>
</tr>
<tr>
<td>“Towards 2020 – Photonics driving economic growth in Europe”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Economic studies published by Photonics21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photonics in Europe, Economic Impact, 2007</td>
</tr>
<tr>
<td>The Leverage Effect of Photonics Technologies, 2011</td>
</tr>
<tr>
<td>Photonics Technologies and Markets for a Low Carbon Economy, 2012</td>
</tr>
</tbody>
</table>
In 2009, Photonics was identified as Key Enabling Technology for Europe by the European Commission. By this Photonics21 got significantly involved in the KET High Level Group. This includes the preparation of the Sherpa Group Interim Report on "Photonics – a key enabling technology for Europe" and the "High Level Expert Group Report on Key Enabling Technologies".

The PPP was proposed by the ETP Photonics21 following an invitation by Vice President of the European Commission Neelie Kroes: "I invited you to engage in an ambitious new public private partnership in the field of photonics. I'm delighted to say that your response to that challenge has been impressive."23

Moreover, Member of the European Parliament Malcolm Harbour stated during the photonics luncheon event in September 2012: “Photonics are synonymous with a modern and technologically advanced Europe. The proposed 7 Billion € partnership between Photonics21 and the European Commission would represent a substantial contribution by this sector towards future growth and job creation, and significantly assist the EU’s continued economic recovery. It will be a major boost for the roll out of the Innovation Union”.

**Photonics PPP implemented through a fully democratic structure based on the ETP Photonics21**

During its meeting on the 29 April 2013 the Board of the ETP Photonics21 has decided to implement a fully democratic governance model closely linked and based on the ETP Photonics21 in order to ensure the broad representation and inclusivity of the PPP. To this end the ETP Photonics21 is establishing a lean PPP Association on top of the ETP Photonics21 which will act as a mouthpiece towards the European Commission in the PPP.

23 Speech Neelie Kroes at the Photonics21 Annual Meeting 2012
By choosing this PPP structure the principle requirements towards a PPP are duly met:

- **Representativeness**
  The Photonics21 ETP represents 2000 members and 1100 affiliations in the field of Photonics. All major stakeholders active in Photonics Research and Innovation as well as end user industries are member of Photonics21 and all different types of stakeholders (ie, industry including SMEs, academia and research institutes, clusters, end-users) are well represented in the decision making bodies of the ETP and the PPP. Photonics21 is to our knowledge the largest PPP in terms of representativeness in Horizon2020. The strategy of the PPP and the Research and Innovation priorities are coordinated with all members.

- **Openness and transparency**
  Photonics21 membership is open to all who are active in the field of photonics on a professional basis (including end users). All procedures are well established and accepted by the members and the European Commission. All positions in the
governance structure are elected by the photonics community following a truly
democratic principle, as this is presented below.

- **Commitment**
  Over the past two years Photonics21 has consulted with its members and the Board. The photonics industry in Europe through Photonics21 agreed to make a significant commitment towards the PPP, namely to invest up to 5.6 billion EUR in Research, Innovation and Manufacturing in Europe in the time frame of Horizon2020.

### Operational structure and decision making process in the PPP

Over the past years Photonics21 has established open, transparent and inclusive operational structures and decision making processes which are widely accepted by its members and the European Commission. This was proven many times over the past years with the establishment of Strategic Research and Innovation Agendas (Roadmaps) and Research and Innovation Priorities for the European Commission Framework Programmes. The European Commission has been and will be invited to closely monitor each individual step in the process.

**The basic principles of the PPP Governance:**

- The ETP Photonics21 **Executive Board** - as elected representative body of the ETP Photonics21 - is establishing the PPP Association which serves as a legal partner towards the European Commission in the PPP.

- The decision making body of the ETP Photonics21, the **Board of Stakeholders**, elects the members of the PPP association (ETP Executive Board) and controls and finances the PPP Association.

- The members of the Board of Stakeholders are directly proposed and are elected by the more than **2000 members of the Photonics21 ETP**.

- The members of the Photonics21 ETP are also responsible for defining the strategic multi-annual research and innovation roadmap of the PPP and for proposing the main research and innovation priorities serving to defining the work programmes of Horizon 2020.

Consequently, as sketched in figure 11, the Photonics21 PPP consists of three organisational layers with following roles and tasks:

- **The Work Groups (WGs)** are the major source of strategy development within the PPP.

- **The Board of Stakeholders (BoS)** reviews the outcomes of the work group strategy and votes on the overall priorities and focus of the PPP.

- **The Executive Board (EB)** executes the decisions of the Board of Stakeholders - through the PPP association - and will be the mouthpiece of the ETP towards the European Commission in the PPP.
Work Groups (People): Strategy Development (Proposal: “Multianual Roadmap” as well as “Research and Innovation Priorities for Horizon2020 PPP work programmes”)
The Photonics21 ETP Membership forms the basis of the Photonics21 PPP. Membership in the ETP Photonics21 will continue to be on a personal basis and open to all concerned with and active in research, innovation and manufacturing in the field of photonics in Europe on a professional basis. This also includes end user industries and European cluster organisations and national technology platforms. Each member (currently >2000) is assigned to a WG according to his/her preference. Thus, all strategic issues to be addressed in the PPP will originate from the WGs.

The WG workshops which were held in 2012 for developing and drafting the current Photonics21 PPP Strategic Multianual Roadmap have attracted more than 400 attendees, and the subsequent electronic consultation generated further contributions for improving the Photonics PPP strategy. This will remain the strong basis for the Photonics PPP in Horizon2020.

Photonics21 WGs cover application and horizontal domains. Application oriented WGs are addressing the most relevant application sectors (markets) for the European Photonics industry. Current application oriented WGs are:

- WG1: Information and Communication
- WG2: Industrial Production, Manufacturing and Quality
- WG3: Life Sciences and Health
- WG4: Emerging Lighting, Electronics and Displays

Horizontal WGs cover the most relevant underlying horizontal technology domains, disruptive research domains or overarching issues like education and outreach. Current horizontal WGs are:

- WG5: Security, Metrology and Sensors
- WG6: Design and Manufacturing of Components and Systems
- WG7: Photonics Research, Education and Training

Each WG has a chair which is member of the Executive Board. WGs can be dismissed / established by the Photonics21 Board of Stakeholders. Decisions at work group level are taken either by consent or if this is not possible by majority voting.

Overview ETP Photonics21 membership:


Board of Stakeholders (Parliament): Prioritization and Decision Making

The respective Photonics21 WG draft strategy documents and research and innovation priorities for the PPP are reviewed and prioritized (by vote, if needed) by the Photonics21 Board of Stakeholders (BoS). Therewith the BoS determines the PPP strategy (like the Photonics PPP Multianual Strategic Roadmap) and a focussed set of Research and Innovation priorities for the Photonics PPP. While the WGs of the Photonics21 ETP are on a personal basis, the BoS membership is institutional and consists of up to 100 affiliations. BoS members are
proposed and elected directly by the WG members (through an appropriate web-based election tool).

The election of the Board of Stakeholders members is made in consideration of

- the standing of the applicant and his/her affiliation and their relevance for pursuing and achieving the objectives of the Photonics21 (PPP).

- the overall composition of the BoS which should be a good reflection of the total group of participants of Photonics 21 in terms of technology fields and geographical coverage. In general, BoS members originating from one European country should not exceed one third of the total BoS members.

- the current and potential future contribution of the applicants and their affiliations to the total platform or within the Work Groups, and the skills they would bring to enhance the BoS.

The BoS endeavours to include in the BoS special interest groups of consumers and end users, European cluster organisations and/or other entities being stakeholders in photonics research and development in Europe.

Current BoS members are well-known reputed decision makers, recognised for their skills in photonics and for representing the wider photonics community. They usually comprise CEOs, CTOs, Heads or Directors of research labs or institutes, high-level representatives of clusters, etc.

In order to guarantee the industry led approach of the PPP, the share of industrial members in the BoS must be at least 50%. The current BoS already provides a rather balanced share between Industry and Research and Technology Organisations/Universities.

![ETP Photonics21 BoS Membership Composition](image)

**ETP Photonics21 BoS Membership Composition**

*Type of Affiliation*

- Large Company: 33%
- Research/Industry/Cluster/ National Technology Platform Association: 7%
- SME: 21%
- Research and Technology Organisations: 38%
- Other: 1%

*Figure 12: Photonics21 BoS Membership Composition*
A BoS member affiliation is not allowed to have more than one BoS representative, unless two or more of these would each represent independent branches of a large European company or research organization, which each substantially contributes to the mission and strategy of Photonics 21.

Decisions at BoS level are discussed at the BoS assemblies and are taken by majority voting, if and when this is required.

In summary this means that the ETP BoS members and their affiliations are the main decision body of Photonics21 ETP as well as of the PPP Association. Their composition is representative of the whole photonics sector in Europe. In respect of this role, all Photonics21 BoS members endorsed the Photonics PPP Multi-annual Strategic Roadmap (see annex) including its industry commitment and Key Performance Indicators.


Executive Board (Government): Execution & Implementation
The Photonics21 Executive Board (EB), democratically elected by the BoS members for a period of two years, is executing the decisions of the Board of Stakeholders and builds the strategic link between the BoS and the WGs. The EB and more specifically the WG chairs within the EB are coordinating the input from the WGs and preparing submissions to facilitate the decision-making process in the BoS. The EB consist of 1 President, 4 Vice Presidents and 7 WG Chairs. The composition of the current Photonics21 Executive Board is shown in Figure 13.
President: Michael Martín, CEO Jenoptik
Vice Presidents: Prof. Malgorzata Kujawinska, Warsaw University of Technology
Giorgio Anania, President and CEO of Aledia
Bernd Schulte, COO Aixtron
Jaap Lombaers, Managing Director Holst Centre

Work Group Chairs:

Information and Communication
Alfredo Viglienzoni, Head New Business Development, Prod., Areas IP & Broadb., Ericsson

Industrial Production Manufacturing and Quality
Lutz Aschke, Managing Director, LIMO Lissotchenko Mikrooptik

Life Science & Health
Stefan Traeger, EVP, Member of the Management Board, Head of Life Science Business, Tecan

Emerging Lighting Electronics and Displays
Klaas Vegter, Chief Strategy and Innovation Officer, Phillips Lighting

Security Metrology and Sensors
Prof. Peter Seltz, Managing Director, Applied Research, Hamamatsu Photonics, EPFL Institute for Microengineering

Design and Manufacture of Components and Systems
Prof. Mike Wale, Director Active Products Research, Oclaro; Technical University Eindhoven

Photonics Research, Education and Training
Prof. Roberta Ramponi, Politecnico di Milano

Figure 13: Current Photonics21 Executive Board
Fair balance between academic and industrial representatives in the Executive Board

According to the mission of Photonics21, namely to foster collaborative research and Innovation between industry and research affiliations, the Executive Board has a fair balance between both groups. Moreover, several individual members of the Board even represent industry and academia at the same time.

<table>
<thead>
<tr>
<th>Executive Board</th>
<th>Executive Board</th>
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<tbody>
<tr>
<td>Industry representatives</td>
<td>Academia and Academia/Industry representatives</td>
</tr>
<tr>
<td>Michael Mertin, CEO Jenoptik</td>
<td>Prof. Malgorzata Kujawinska, Warsaw University of Technology</td>
</tr>
<tr>
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</tr>
<tr>
<td>Bernd Schulte, COO Aixtron</td>
<td>Prof. Peter Seitz, Managing Director, Applied Research, Hamamatsu Photonics; EPFL Institute for Microengineering</td>
</tr>
<tr>
<td>Alfredo Viglienzoni, Head New Business Development, Prod. Areas IP &amp; Broadb., Ericsson</td>
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<td>Prof. Roberta Ramponi, Politecnico di Milano</td>
</tr>
<tr>
<td>Stefan Traeger, EVP, Member of the Management Board; Head of Life Science Business; Tecan</td>
<td></td>
</tr>
<tr>
<td>Klaas Vegter, Chief Strategy and Innovation Officer, Philips Lighting</td>
<td></td>
</tr>
</tbody>
</table>
Overview: PPP decision making process

The PPP decision making process is described in Figure 14. The PPP foresees a dedicated Key Performance Indicator to monitor the Efficiency, openness and transparency of the PPP consultation and decision making process (see KPI 8 above) as this will be decisive for the success of the PPP. The monitoring will be done jointly with the European Commission.

Figure 14: Decision making process within the PPP: Multiannual Roadmap & Research and Innovation Priorities
PPP Association – role and responsibilities

The PPP Association is formally consisting of the Photonics21 ETP EB members. It is established as a Non-Profit Association under Belgium Law. The PPP Association is tightly linked to the ETP Photonics21 and its decision making body, the BoS. Consequently, the PPP Association is financed by the Photonics21 BoS through service contracts between the PPP association and the BoS member institutions. Indeed, the members of the association sign a legally binding association membership agreement to ensure that any decisions taken by the PPP Association on Photonics21 matters are in line with the Photonics21 BoS decisions.

Excerpt of the PPP Association Membership Agreement24:

**Photonics 21 Matters**

- Any decision to be taken by the Parties as Members of the Association that are related to Photonics 21 Matters, shall be voted upon by their Representatives in the General Assembly, and such voting shall always be fully in line with the decisions taken on the same Photonics 21 Matters by the Photonics21 B.o.S.

- In case a Representative does not vote on one or more Photonics 21 Matter in accordance with the decision taken in that respect by the Photonics21 B.o.S., this shall amount to a material breach, as referred to in Article 9.3, of the Party that employs such Representative.

- Each Party shall ensure that its Representative shall comply with all provisions of this Agreement and of the Articles of Association relevant to it, and in particular shall vote in accordance with the first paragraph of this Article, as well as with Article 2.4 hereof.

The Photonics PPP Association members can be dismissed by the ETP Photonics21 BoS.

Any obligations of the PPP like the industry commitment or the monitoring of Key Performance Indicators are conducted by the PPP Association and its secretariat in close coordination and cooperation with the ETP Photonics21 and more specifically with the ETP Photonics21 BoS.

**Photonics PPP Association – ETP Photonics21 Executive Board**

As mentioned above, the Members of the ETP Photonics21 Executive Board form the Members of the Photonics PPP Association and the President of the ETP Photonics21 Executive Board is at the same time the Chairman of the PPP Association.

The task of the PPP Association is to overlook the PPP development and follow and assess the progress on Key Performance Indicators described above.

The ETP Photonics21 BoS will be regularly informed about the progress of the PPP and will decide on any corrective actions to be taken by the PPP Association if deemed necessary.

**Photonics PPP Association - Secretariat**

The Association will establish a Photonics PPP Secretariat which will be tasked to collect jointly with the European Commission relevant information on the PPP.

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24 Draft state at the moment
25 ETP Photonics 21 Matters means those subjects that are related to the Strategic Research and Innovation Agenda (Multi Annual Roadmap) and to the priority setting towards the Horizon 2020 PPP work programs, derived from the Strategic Research and Innovation Agenda
More specifically the secretariat will

- Prepare regular progress reports on the PPP;
- Co-organize with the European Commission regular Horizon2020 PPP Project progress and project clustering meetings to assess progress of PPP projects in relation to the PPP roadmap;
- Provide all relevant information on the Photonics PPP to the Association (and the Photonics BoS) to judge on the progress of the PPP.

The PPP Association is currently established and will be operational by November 2013 to sign the contractual arrangements with the European Commission on the contractual Photonics PPP.

**Involvement of regional and Members State Stakeholders**

One of the principle aims of the PPP is to better align the European Photonics strategy with national and regional strategies and policies and become more efficient in terms of implementation and creating value chains across different Member States. However, this can only be successful if a close alignment of the PPP strategy and implementation is coordinated with regional and national stakeholders.

This will be done on two levels:

**Level 1: Photonics National Technology Platforms and Regional Clusters**

The National Technology Platforms and Clusters are closely involved in the Photonics21 Work Groups and many of them belong to the decision making body (BoS) of the ETP Photonics21. Therewith regional and national strategies are closely reflected in the PPP strategy. Moreover, the PPP will take an active part in supporting Platforms and Clusters to implement the European Commission Strategy on Smart Specialisation and to build up photonics manufacturing capabilities in the regions.

![Figure 15: Photonics National Technology Platforms and Clusters in Europe](image-url)
**Level 2: Photonics21 Mirror Group**

The activity above is complemented by the Photonics21 Mirror Group consisting of public authority representatives from Members States and regions which – based on the strategic input derived from the PPP – agree on joint funding activities (via the ERANET+ instrument) and efficiently implement the PPP strategy.

To this end the aim of the Mirror Group is to:

- Support and reflect (“mirror”) the activities of the PPP at policy level and from a governmental perspective;
- Support the implementation of the Photonics Strategic Research and Innovation Agenda / the Photonics Multiannual Strategic Roadmap;
- Exchange best practice and promote photonics in national and regional research programmes;
- Create and prepare joint strategies, measures and activities at government and policy level.

As a starting point three ERANET+ calls have already been implemented by the Photonics Mirror Group:

- Internet Access Networks,
- Organic Electronics (Photonics),
- Photonic Appliances for Life Science and Health

The aim of the PPP is to have truly coordinated and complementary activities at regional, national and European level within the PPP. Currently 15 members states are represented in the Photonics21 Mirror Group (see Figure 16).

![Figure 16: Members states represented in the Photonics21 Mirror Group](image)

**Milestones of the PPP**

**Milestones / Outputs for Year 1:**

- The definition and full implementation of the photonics PPP governance structures and secretariat
  - Target: 1st half 2014
- Contribution to the definition and dissemination of the first Horizon 2020 work programme of the PPP for 2014-15
The establishment of the Partnership Board of the photonics PPP (which is the main mechanism for dialogue to monitor and reach the objectives of the PPP)

- Target: First half 2014
- Target: 2nd quarter 2014

Milestones for the Photonics PPP for the subsequent Years

- Photonics21 annual events bringing together all the Stakeholders
- Monitoring of the functioning of the Photonics PPP (incl. the degree of satisfaction of the Photonics Stakeholders) and of its Partnership Board.
- Target: Before every annual event of the Photonics PPP
- Monitoring the degree of implementation of the photonics multi-annual R&I agenda and delivering a prioritised list of R&I activities for the definition of the Horizon 2020 bi-annual work programmes. Target: by December every second year (to be delivered by the Photonics21 secretariat in cooperation with the European Commission Photonics Unit)

Additional contributions

- Contribution to the mid-term assessment of the Photonics PPP: 2017 (By the Photonics21 secretariat in cooperation with the European Commission Photonics unit)
- Photonics world Market studies in 2016 and 2019 – 2020

**Dissemination and Outreach Activities**

The basic principle of the PPP and more specifically of the PPP projects is the sharing of information among and beyond the Photonics community respecting IPR issues within individual companies. On the PPP (and its processes and results) itself all information on the strategic road mapping and the PPP Research and Innovation priorities will be made public.

However, regarding the implementation of the PPP a sophisticated dissemination concept of the Photonics PPP will be applied that goes far beyond the pure sharing of information, but will rather pro-actively support the innovation process of the PPP.

To this end the dissemination of the Photonics PPP will address 4 dissemination levels:

**Level 01: Involve end consumers and end user industries in the PPP implementation process**

The preparation of the PPP Multi-Annual Roadmap was done by a broad involvement of end user industries already. However, with regard to the implementation of the PPP it will become even more important to not only follow the traditional path of innovation, but find new ways of inventing sophisticated products. By closely involving end users in the implementation process working in technology silos will be avoided. To this end also the open innovation concept will be applied within the Photonics PPP. Whereas some photonics companies (mainly bigger ones) have already applied open innovation models this is not widely adopted by the photonics industry so far. The PPP will pro-actively push for and enable a more dynamic innovation and information sharing process involving new innovation models and multi-directional communication, from big companies to small companies, from regional/national to European level and vice versa. This includes open innovation workshops involving large companies, SMEs

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but also end users that are traditionally not addressed in technology oriented Framework Programme innovation activities e.g.

- Architects and Designers in the case of Solid State Lighting
- End consumer communities (e.g. makers\(^27\)) in the case of 3D Laser printing
- Automotive/Aviation and other manufacturing industries in case of Laser Manufacturing
- Medical Doctors in the field of Biophotonics

Results of these activities will be included in the further Photonics PPP strategy implementation.

**Level 02: Coordinate the PPP implementation with members states and regions**

It will be of outmost importance for the success of the PPP that the strategy implementation will be closely coordinated and combined with regional and national activities in the field. Moreover, specific PPP activities like access services (manufacturing and prototyping) for SMEs will only be successful if information about the new opportunities is disseminated properly to the respective companies. To this end, Clusters and National Technology Platforms in close cooperation with the PPP will have an important role to play in the dissemination of opportunities to the relevant companies in the regions. Coordination will be done through regular workshops with clusters and national platforms followed by communication through these organisations. Already, monthly information is provided via a newsletter to more than 2000 professional experts in Photonics in Europe to inform about recent activities and opportunities. This will be further expanded in the frame of the PPP.

**Level 03: Attract more students to Photonics and address the skills shortage in Europe**

Despite the fact of high unemployment rate in Europe, European Photonics industry is facing a shortage of skilled personnel. Not enough students undertake photonics curricula at our universities. To this end dissemination and outreach actions will be implemented to inspire and motivate young minds. Actions will take advantage of the “United Nations International Year of Light”\(^28\) 2015 for massive dissemination. Easy but fascinating exhibitions will be organized in crowded environments (airports, stations, shopping malls); Universities and research centres should program open days through the organization of living labs and fab labs; furthermore, educational kits equipping teachers with class set of experimental photonics material provided within a supporting didactic framework will be disseminated to schools across Europe. Activities will include Research and Technology organisations, universities and companies.

**Level 04: Make Photonics more visible to the general public in Europe**

It is regarded as specific task of the PPP to provide information and tangible examples about how Photonics solutions contribute to the day to day live of European citizens. Success stories from PPP projects and more widely innovative Photonics research with some clear implication on products, jobs and societal challenges will - in cooperation with the European Commission - be circulated to the general public through various communication channels like social media, print, video. In anticipation of the PPP a Twitter account has already been established with at the moment more than 300 followers. The activities will be tightly coordinated with national and regional actors to get the most possible impact.

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**Annex: Photonics21 Multi-Annual-Roadmap**

\(^27\) Makers: The New Industrial Revolution; Chris Anderson, 2013

\(^28\) [http://www.eps.org/?page=event_iyol](http://www.eps.org/?page=event_iyol)
TOWARDS 2020 – PHOTONICS DRIVING ECONOMIC GROWTH IN EUROPE

Multiannual Strategic Roadmap 2014–2020
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Executive Summary

The rise of photonics in Europe from a niche activity to a Key Enabling Technology, and on to becoming one of the most important industries for the future, shows how photonics is on its path to making the 21st century that of the photon.

Photonics is everywhere around us: from communications and health, to materials processing in production, to lighting and photovoltaics and to everyday products like DVD players and mobile phones. Yet the full disruptive potential of photonics is only now becoming clear. New advances in photonics will revolutionise healthcare and provide new ways of detecting, treating and even preventing illness. In manufacturing, laser processing will be a basic prerequisite for high-volume, low-cost manufacturing. Photonics technology will help overcome the limitations of electronics in computers through all-optical computing or even quantum computing. Photonics will move communications into the terabit era by dramatically increasing data capacity and data transmission speeds, while simultaneously reducing the networks’ carbon footprint and the overall cost per bit. Photonics will play a key role in addressing the challenges of energy efficiency and moving to a low-carbon economy. In the future, solid-state light sources are expected to outperform almost all other sources in terms of efficiency, offering potential energy savings of 50% or even more, when used with intelligent light management systems. Sensor applications in smart power grids, smart buildings and smart industrial process control will contribute significantly to more efficient use of resources and meeting environmental challenges.

Through the long-term commitment of all parties to a common shared vision, the proposed Photonics Public Private Partnership (PPP) in Horizon2020 will lead to a more competitive photonics sector in Europe. Embracing the main recommendations of the Key Enabling Technologies (KETs) initiative, the Photonics PPP will be vital for achieving the critical mass necessary for developing a coherent application oriented and market needs driven technology & innovation, and for strengthening RDI capabilities across the full value chain, from research to manufacturing and from materials to OEMs & end users. It will develop and implement an integrated RDI programme that fully meets the needs and priorities of markets, and tackles the ‘valley of death’ problem by undertaking strategic projects. Continued close collaboration with member states 1 will be critical for the success of this PPP.

1 through the Photonics21 Mirror Group
Underpinning all the proposed activities is the objective of growing photonics manufacturing in Europe and creating further ‘high skill’ employment. This will be achieved by enabling the photonics products themselves to be manufactured in Europe, and by ensuring the ongoing competitiveness of other key photonics-dependent manufacturing sectors in Europe.

The proposed Photonics PPP will differ from the existing support mechanisms by establishing a closer alignment of industrial and public strategies, and by pooling academic, industry and public resources to provide sufficient know-how and the investment essential for achieving major progress towards this joint strategy. Applying an open innovation process will help achieve the specific aim of the PPP to establish a more effective translation of scientific research into products. In recognition of the importance of forming a PPP, the European Photonics Industry undertakes to make a substantial commitment through a four-fold leverage of public funding to achieve a total investment of €7 billion (€5.6b from the private sector and €1.4b from the European Commission).

**Added-value for Europe through strengthened industrial competitiveness**

The photonics global market is today around €300 billion. Europe has established a strong position with an overall total share of 20%, and as much as 40% in key sectors such as lighting. The European photonics industry employs about 290,000 people directly, many of these in the over 5000 photonics SMEs. Photonics also has a substantial leverage effect on the European economy and workforce: 20-30% of the economy and 10% of the workforce depend on photonics, directly impacting around 30 million jobs. Photonics also offers solutions which address key societal challenges, such as energy generation and energy efficiency, healthy ageing of the population, climate change, and security.

Photonics is a Key Enabling Technology for Europe. It is a very dynamic and vibrant industrial sector in Europe and holds the potential for huge market growth. The expected compound annual growth rate for photonics over the coming years is 8-10%, clearly demonstrating the rapid growth of this key technology sector. In specific areas, substantially higher growth rates are predicted, for example, in green photonics the expected CAGR value is nearer 20%.

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3 Green photonics comprises photonics solutions that generate or conserve energy, cut greenhouse gas emissions, reduce pollution, yield environmentally sustainable outputs or improve public health.
Europe now needs to build further on its strong position in the global photonics markets, and it will be crucial to align and coordinate this highly multidisciplinary and fragmented field. It needs to strengthen its industrial leadership by promoting wide-scale cooperation and greater integration across the whole research and innovation value chain, from advanced materials to manufacturing, and from advanced research to technology take-up, pilot lines and demonstration actions. A Photonics PPP is seen as the optimal vehicle for achieving this development.

Particular emphasis needs to be given to supporting the innovation of the large number of SMEs active in this area and helping them grow further to become global players.

**Main activities for the Photonics PPP**

The dual challenge facing Europe is both to lead in photonics technology innovation, and to exploit these results through successful commercialisation. In this way, the goals of solving the grand societal challenges and of generating sustainable economic growth in Europe can be met. By implementing this strategy, the 21st century can truly become the century of the photon.

The potential Research and Innovation activities best placed to address these challenges and objectives are:

- **Disruptive and road-map based core photonic technologies**
- **Roadmap-based research** will be undertaken to drive technological development and innovation in strategic application areas where Europe is strong. These strategic application areas include optical data communications, laser manufacturing, biophotonics for medical and biomedical applications, imaging and sensing for safety, security and the
Executive Summary

The emphasis will be on broader cooperation across the whole research and innovation value chain and the close involvement of end-users, including citizen groups where appropriate.

**Disruptive technology breakthroughs** in nanophotonics, quantum information, extreme light sources, etc., will be pursued, complementing the roadmap-based research, and bringing the potential for disruptive innovation in support of future European leadership.

**Demonstration**

Specific deployment programmes using photonic innovations will be needed to demonstrate social innovation and leverage EU infrastructure to create jobs. Such infrastructural projects could provide benefits to all 500 million people in the EU, and not solely to those directly involved in the photonics industry. Deployment programmes would be focused on life cycle and applications.

In this way, coordinated market pull/push measures will seed and then accelerate market penetration, ultimately leading to wider technology adoption and consequent job creation. Measures would include the launch of high-visibility, demonstration projects that provide the European photonics industry with a first-mover advantage in the global market.

**Photonics Manufacturing Platforms**

Underpinning all the proposed activities is the objective of growing photonics manufacturing in Europe and creating further high skill employment. This will be achieved at two levels; enabling the photonics products themselves to be manufactured in Europe, and ensuring that other key manufacturing sectors in Europe, dependant on photonics technology, can remain competitive. To this end the following measures would be implemented:

- Improvement of the infrastructure for photonics manufacturing in Europe. This involves making full use of the existing manufacturing excellence of research institutes for supporting industry, especially innovative SMEs. The creation of such generic photonic foundries, based on public-private partnership, will enable cost-effective and widespread deployment of photonics technology in numerous applications, and ultimately lead to volume production.

- Establishment of pilot production facilities, in which industry and research institutes can jointly develop innovative photonics production processes, targeting applications relevant to societal challenges and economic growth.

Since the value chains in specific photonics application areas in Europe are fragmented across different member states, demonstration activities and manufacturing platforms are expected to reinforce the innovation ecosystems at local (smart specialisation) and European levels.

**Innovative photonics SMEs**

SMEs lie at the very heart of the European photonics industry, and play a major role in driving innovation and economic growth. It is essential for the future prosperity of the European photonics industry, and thereby of European society, that their competitiveness in the global market is sustained and grown further. Take-up of and RDI support for innovative photonics technologies through ‘light touch’ open schemes will be promoted. The emphasis will be on strengthening the competitiveness of European SMEs, and on the creation of new business opportunities.

To this end, a fast-track funding vehicle for photonics SMEs is envisaged within the Photonics PPP. Further synergies with regional innovation clusters will be established to promote SME
development through, for example, establishment of open innovation models along the value chain. This would allow SMEs to operate within a streamlined, more market-oriented set of rules, allowing prototype development for shorter-term commercialisation, rather than being limited only to precompetitive R&D.

**Strengthening Photonics Foundations**
The actions of the Photonics PPP will be accompanied by measures on education, training and skills development, as well as standardization, international cooperation & outreach. Both industry and academic partners of the PPP will undertake these actions to secure the future workforce for this growing industry.

All activities will be accompanied by measures to better attract sufficient capital and management support for seeding and growing innovative business ideas.

The PPP will work towards the establishment of a dedicated European industrial growth fund, leveraging existing investments in photonics innovation through to commercialisation.

**Photonics for the Societal Challenges**
Photonics has a critical role to play in addressing several key challenges identified by the Europe 2020 strategy.

- **In healthcare, demographic change & well-being** photonics will provide new ways of detecting, treating and even preventing major diseases at the earliest possible stage, improving patient survivability and drastically reducing care costs.

- **In climate action, resource efficiency & raw materials**, new laser-based photonic manufacturing technologies will stimulate new manufacturing processes with extraordinary quality.
that will allow mass customisation, rapid manufacturing and zero-fault production. Photonics will also stimulate the lighting transition from incumbent technology to a low energy consumption, digital technology, built around LEDs, OLEDs, sensors and microprocessor intelligence, contributing to saving energy and money, and increasing visual comfort and well being.

- For inclusive, innovative and secure societies, photonics will increase information access for all citizens, through the development of the future Internet infrastructure with multi-terabit capacity, while reducing the networks’ carbon footprint and the overall cost per bit. Such Internet infrastructure will leverage the development of new products and sophisticated applications services that fully exploit this connectivity, with huge potential impact on European society in all areas of human activities. Photonics based sensing and imaging will enable higher levels of security and safety through the use of sophisticated surveillance technology and detection of unauthorised goods, as well as contributing to a greener environment through providing advanced pollution detection.

The Photonics PPP will work closely with other players involved in addressing these societal challenges, in particular with Smart Cities, Active and Healthy Ageing, and Resource-Efficiency.

**Implementing the Photonics PPP Multiannual Roadmap**

Implementing the Photonics Multiannual Roadmap, which has been widely endorsed by the Photonics community in Europe, will be the key objective for a Photonics PPP in *Horizon 2020*. The roadmap recommends that Europe needs to strengthen its ability to make the critical transition from successful innovation in photonics to the industrial deployments necessary for job creation. Bridging this gap must be a key objective of the Photonics PPP. For photonics to yield its full potential as an enabling technology, it will be critical that the inherent synergies within the sector are exploited through integrated research aimed towards identified market solutions, rather than towards isolated components or applications.

Finally, it is recognised that disruptive photonics research is of major importance for maintaining its long-term competitiveness. Therefore, photonics disruptive research, and in particular, research into Organic and Large Area Electronics, will play a significant role within the PPP.
Introduction

The preparation of the Photonics Multiannual Strategic Roadmap has been driven by the European photonics community and the European Technology Platform Photonics21 to foster the set up of a Photonics Public Private Partnership (PPP) within the new Framework Programme Horizon 2020. During the roadmapping process, the photonics community and the Photonics21 Work Group Chairs engaged in a close dialogue with the European Commission Photonics Unit of DG Connect.

The Photonics Strategic Multiannual Roadmap is the result of extensive brainstorming and discussions with more than 300 experts from the European photonics community. They have identified strategically important photonics research and innovation challenges as well as crosscutting Key Enabling Technology issues, and have outlined the need for Europe to invest further in these identified application areas and photonics technologies.

The scope of the Photonics Multiannual Roadmap is to provide photonic solutions to the major socio-economic challenges of Europe, such as to the ageing society, health, energy-efficiency, food safety and security. Furthermore, the European photonics community aims to implement the long-term photonics research and innovation strategy elaborated in this Multiannual Roadmap.

As an introduction to the Photonics Strategic Multiannual Roadmap, chapter 1 provides the main strategic objectives and outlines the vision of the European photonics community for future photonics research and innovation (section 1.1). This is followed by a discussion of the proposed Key Performance Indicators that will be used to measure the success and impact of European research and innovation funding under the new Framework Programme Horizon 2020 (section 1.2). Finally, the introduction outlines the role played by photonics innovation ecosystems in Europe. (section 1.3).

Chapter 2 of this report, Photonics Research and Innovation Challenges, outlines the specific research and innovation areas envisaged by the seven Photonics21 Work Groups within the framework of the Photonics PPP. Each Work Group has defined relevant research and innovation areas, and has also produced a series of roadmap tables for the full planned duration of Horizon 2020, covering 2014–20.
Finally, to conclude the Photonics Strategic Multiannual Roadmap, chapter 3 outlines the expected impact and benefits of a Photonics PPP for future photonics research and innovation in Europe. Details of the consultation process used to construct these technology roadmaps are presented in Appendix 1.

1.1 Strategic Objectives and Vision

Today, the global market for photonics is estimated to be approximately €300 billion, and the leveraged impact of photonics in other enabled industries is substantially greater in terms of turnover and employment levels. This market is expected to grow significantly over the next few years, with the estimated market size approaching €480 billion by 2015.

Europe has an overall share of 20% of this global market, which corresponds to approximately €60 billion. The European market share rises to as much as 45% in certain specific key photonic sectors, such as lighting, for which many market-leading industrial players are located in Europe. Europe also has particularly strong positions in industrial laser technologies, information and communications technology (ICT), and biophotonics.

The annual market growth rate of photonics in Europe is estimated to be between 8–10%, which is 2–3 times faster than the overall European GDP growth. In specific areas, substantially higher growth rates are predicted, for example, in green photonics the expected CAGR value is nearer 20%.

‘Green photonics’ is the term used to encompass the application of photonics technologies that can generate or conserve energy, cut greenhouse gas emissions, reduce pollution, yield environmentally sustainable outputs, or improve public health.

The European photonics industry currently employs about 300 000 people in Europe. As the photonics sector is largely based on SMEs (there are about 5000 photonics SMEs in Europe), growth in demand is known to create proportionally more jobs than would typically be seen in a sector made up primarily of big companies.

**Funding along the full Innovation Value Chain in Europe**

Europe performs a major proportion of the world’s research into basic photonics and achieves excellent R&D results, providing Europe with a world leading position. However, Europe needs to strengthen the industrial deployment of these research results by promoting wide-scale cooperation and greater integration across the whole research and innovation value chain. Therefore, it is necessary to rebalance the funding within the new Framework Programme *Horizon 2020*, so as to provide an increased budget of funding to applied research and demonstration programmes for photonics.

The European photonics industry must now continue working with the European Commission and national policy makers to coordinate a joint approach to innovation, and to pool investments for enabling the rapid development of new products and minimising times to market. This speed...
to market approach needs to include the entire value chain, from advanced research through to technology take-up, pilot lines, and manufacturing platforms.

Bridging the gap between excellent research results and product development, and thus overcoming the so-called Valley of Death, must be the key element of a photonics strategy for future research and innovation funding in Europe. This funding approach should be implemented within the new Framework Programme Horizon 2020.

**Integrated approach to bridge the Innovation Gap**

The European photonics community proposes a multiple approach for how the Valley of Death problem can be overcome and the innovation gap bridged. Actions are required in the following areas:

- **Disruptive and roadmap-based core photonic technologies**
  - Roadmap-based research with a value chain approach
  - Recognised value of potentially disruptive innovations
  - Early involvement of end-users

- **Demonstration programmes**
  - Deployment programmes to create new jobs in Europe
  - Showcase public authorities’ commitment to invest in photonics
  - Accelerate market penetration

- **Manufacturing Platforms to maintain manufacturing in Europe**
  - Improve infrastructure for photonics manufacturing
  - Establish public-private pilot production facilities for industry and research institutes
  - Reinforce innovation ecosystems at local and European levels

- **Innovative Photonics SMEs**
  - Fast-track funding to foster prototyping & short-term commercialisation
  - Reduced administrative burden for SME participation

- **Support Actions**
  - Develop a highly skilled workforce
  - Photonics education, training & skills development
  - Outreach activities to promote photonics to education providers
  - Standardisation

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Left: Europe has an overall share of 20% of the global photonics market. © Fotolia

Right: The European photonics industry currently employs about 300 000 people in Europe. © Fotolia
To support this value chain oriented approach, three additional drivers are identified that would greatly enhance its effectiveness:

- The European Commission identified photonics as being one of the Key Enabling Technologies (KET) for Europe. The European photonics community firmly believes that Horizon 2020 should have a clear focus on this KET to ensure a critical mass of funding budget is achieved.
- Access to venture capital and dedicated SME support should be facilitated within Horizon 2020.
- The new Framework Programme should be simplified significantly for greater flexibility, so that the administrative burdens, particularly for SMEs, associated with proposing and participating in a project can be minimised.

**Photonics Public Private Partnership in Horizon 2020**

The photonics community is ready to invest in Europe’s long-term competitiveness and growth, and to provide a four-fold leverage of the European funding through private investment. This would sum up to an overall amount of approximately €7 billion.

The photonics community strongly favours a Photonics PPP that would result in a long-term funding commitment, and would be set up as an equitable partnership between the European Commission and the photonics community. To turn this Photonics PPP model into reality, the photonics community asks for lean, simple and efficient structures and procedures. A Photonics PPP structure under Horizon 2020 should build upon the success of the European Technology Platform Photonics21, with its reputation and established transparent decision-making procedures. Furthermore, the Photonics PPP should not lead to the disruption of the Photonics community in Europe that has been built up successfully over the last 7 years.

Additionally, the European photonics community undertakes to measure the success of the Photonics PPP by Key Performance Indicators.

### 1.2 Key Performance Indicators

Throughout the course of the Horizon 2020 programme and the operation of the Photonics PPP, a key feature will be the long-term industry commitment to assess and quantify the level of investment occurring in the field of photonics research and innovation in Europe.

Specifically, the European photonics industry’s undertaking to leverage the initial European Commission public funding investment in Europe by a factor of four will be assessed. This commitment will be based on the aggregate performance of the photonics industry partners, rather than that of individual companies. For this assessment, Photonics21 proposes to monitor all companies that participate in Horizon 2020 Photonics PPP projects between 2014 and 2022.

The monitoring would provide a more complete picture of the industry investment of participating companies, and could be confirmed as part of the contract negotiation phase for all industrial participants in new Horizon 2020 projects. Beneficially, this monitoring of all participating companies will also facilitate the generation of valuable sub-sector specific data.

As their primary Key Performance Indicator, each participating company would provide one overall figure, summarising their company's investments in the photonics area. An accounting firm or similar professional service would perform the monitoring, thereby ensuring a clear commitment to confidentiality, and being demonstrably independent of either parties in the Photonics PPP.

The photonics community is ready to invest in Europe’s long-term competitiveness and growth and to provide a four-fold leverage of the European funding through private investment.
In addition to monitoring direct company investment, an independent macroeconomic study would be conducted on an annual or biannual basis. Photonics21 proposes that an independent organisation will conduct this macroeconomic study to monitor the overall impact of the PPP and the state of the photonics sector as a whole. All participating companies would be required to provide information to the organisation conducting the macroeconomic study.

### 1.3 Photonics Innovation Ecosystems in Europe

The European photonics landscape is made up of high-level research groups and a strong photonics industry, consisting of both SMEs and large companies. Most of these photonic players are active in regional innovation clusters and national technology platforms.

Regional innovation clusters are composed of large companies and SMEs, start-up companies, public and private research centres, universities, specialised suppliers, investors, and regional & government agencies within a geographic region. They work together in a partnership to follow a common photonics regional development strategy, devised to create synergies in a specific photonics application area.

European and national technology platforms are networks formed between private and public players, working together on common strategic photonics topics to define a common national photonics strategy and promote greater political visibility for photonics.
Regional innovation clusters and national technology platforms each represent the interests of the photonics community at a regional and national level. To ensure that photonics becomes part of the regional or national innovation strategies, direct and effective engagement with regional and national governments will be essential. Furthermore, photonics clusters and platforms provide a centre of gravity and a critical linkage between the Photonics PPP and regional activities, and, through this, will help define strategic research and innovation directions at the European level. The development of photonics clusters and platforms is an ongoing process, and we do expect to cover a ‘large area’ of EU at regional level and all countries at national level.

The EU acknowledges the importance of national technology platforms and regional innovation clusters for developing further the photonics innovation capacity needed in Europe, and strengthening the innovation value chain. Specifically, these regional structures now have the critical mass to define strategic directions at regional and national level. Consequently, they are expected to play a key role in Smart Specialisation, the EU’s strategic approach for Structural Fund investments in R&I, aimed at maximising knowledge-based development potential at the regional level.

It is vital therefore that the photonics regional innovation clusters and national technology platforms continue their cooperation and work together with the Photonics PPP, developing greater community cohesion and pursuing a common photonics R&I strategy on a European scale, with further involvement of new regional clusters and national platforms. In this way, the national technology platforms and regional innovation clusters will provide a critical link between Horizon 2020, national and regional strategies, and European regional development funds to define and implement the Photonics PPP strategy and guide R&D funding to innovative European SMEs.
Photonics Research and Innovation Challenges

The following sections have been prepared by the Photonics21 Work Groups. The photonics research and innovation challenges being faced are outlined for each of the different photonics application fields. In particular, discussion is presented of how each field addresses the socio-economic challenges, and of which value chain partners should become involved in photonics research and innovation.

2.1 Information & Communication

Main socio-economic challenges addressed

Severe challenges must now be faced that could have major potential impact on Europe's prosperity and sustainability: ensuring sustainable development, securing energy supply, addressing the needs of an ageing population, and ensuring human and environmental health. In addition to these challenges, a key focus must be achieving secure employment across Europe over the coming years.

Information and communication technologies (ICT), underpinned by optical broadband communication technologies, will address many of these socio-economic challenges. ICT supports and enables new ways of living and managing resources. ICT and related applications will offer new job and wealth opportunities, providing people living in secluded areas the same opportunities as those living in large cities.

Additionally, broadband communication technologies significantly reduce carbon emission, and enable most of the services used within our homes, from education to work, from government to health, from entertainment to security. In most advanced countries, education and technically advanced home-based work environments are enabled through broadband communication services.
We will soon live in a world in which everything that could be connected will be connected. As well as connecting homes, broadband technologies will also connect businesses, equipments and infrastructures for research and production, opening up new commercial opportunities and enabling different ways of living. All these solutions will need photonic systems and technologies, because they are the only possible way to sufficiently reduce energy consumption, whilst still providing the high levels of performance demanded. Photonics is the enabling technology for all wireless and wired broadband technologies.

Demands for connectivity and data are growing exponentially. Moreover, information storage, management and security will require new, dedicated solutions to match these demands. All such challenges will need broadband access to network resources, a high capacity flexible network, and a large number of network environments, such as datacentres, power grids and research infrastructures.

In addition to these challenges, increasing global competition from APAC (China, India) and the US requires greater innovation and more entrepreneurship in Europe to reinforce and grow its leading role. The ability of European industry to customise and provide successful end-to-end solutions, particularly photonic solutions, will be the key to securing future employment for Europe.

**Major photonics needs**

Photonic systems and networks, architecture and functionalities must undergo significant changes to cope with new applications. With the growing concern about energy efficiency and carbon emissions, significant changes are necessary in all network layers and segments (core/metro/access/datacentre). Moreover, major needs exist to make the networks faster, more secure, more flexible, more transparent, easier to use, and to bring them closer to the customer. Functionalities for which photonics can bring unique advantages, have to be addressed. These will primarily be high-capacity, high-speed and low latency transmission of data between arbitrary end-points, and could also extend into areas such as encryption, switching, quantum communication and computing.

Novel and disruptive techniques are required to cope with the ever-increasing demands for capacity, especially in the backbone networks, for which a transmission capacity of several times 100 Tbps per fibre is predicted by the year 2020. Today the growth in datacentre traffic is demanding more energy efficient ways of computing and moving data across the network. Photonics opens up exciting opportunities to provide solutions for this challenge.
opportunities for solving the bandwidth limitation of data interconnects at rack, board and chip level.

A major challenge for the coming years will be the development of high-bandwidth, low energy consumption optical interconnects at low cost. New services, such as cloud computing require significant improvements in the network architecture and high-speed (fibre-based) access to the customer.

Efficient production of photonic systems and photonic integrated circuits (PICs) is a major need. Significantly more bandwidth is required for next-generation applications in computing and storage, in communication infrastructure, and in the access market. By integrating programmable electronic and photonic circuits in a single package, such optical ASIC or FPGA technology can break through the reach, power, port density, cost, and circuit board complexity limitations of conventional solutions. In this context, an efficient production of PICs will be essential. Photonic integration will play a key role in reducing cost, space and power consumption, and improving flexibility and reliability. Additionally, development of simple and robust on-chip test capabilities and generic packaging and assembly options will be required for achieving cost efficient production processes.

Overall, it is evident that the development and product introduction of advanced photonic technologies will require significantly more financial resources than in the past, thereby exacerbating the risk that, if Europe is unable to raise sufficient budgets, such technologies will move to APAC.

**Involvement of value chain partners**

The involvement of end-users is extremely important for developing bespoke photonic solutions, which match to the end-users’ specific needs. This is especially important, for example, when building new networks such as smart power grids, which are expected to incorporate new technologies and end users, and will be managed and controlled by advanced photonic communication technologies.
This also applies to applications such as the Internet of Things for ambient assisted living or health care services, and in smart city environments. Involvement of the end-users allows for enhanced testing and the creation of new applications and services at early stage. The tight coupling of information and communication technologies in end-user solutions will illustrate effectively the leveraging effect that photonics communication technologies bring to Europe. Focusing on the development of customised end-to-end solutions has the potential of anchoring technology development, growth, and jobs in Europe. It creates additional business opportunities for eco-system partners, focusing on the adaptation of such solutions to varying regional requirements.

Stimulating interaction between research institutes, universities and industry is required to identify applications and related R&D, where photonics can bring unique advantages. Creation of open innovation centres can help to foster this collaboration. Moreover, Europe needs to invest in education and science for developing people and their ideas. Education and advanced training of engineers and scientists is required at a high level to increase the level of innovation in optical communication components, sub-systems, systems and networks. A number of successful European projects have already been instigated in this direction, such as ePIXnet, ACTMOST, and EUROFOS. Institutionalising such interactions within the Work Groups of Photonics21 could provide a sustainable, open, transparent and European-wide collaboration involving all the major stakeholders. Current approaches could be beneficially extended to include direct interaction between the stakeholders, such as concertation, consultation and roadmapping for new research and innovation activities, establishing ad hoc collaborations between members, and exchanges of people and resources. The scope and structure of Work Groups must be sufficiently dynamic to allow for new developments and the incorporation of new stakeholders as photonics evolves and new paradigms appear on the horizon, whether they be in technology, business models, or the value chain.

An effective venture capital culture, similar to that in US that allows a rapid ramp up of innovations towards the market, should be established for European photonics SMEs, who provide the engine for industrial growth in our high-tech society, and who need access to capital in order to capture the economic value of innovations. In this respect, the provision of funds for facilitating access to capital for photonic start-ups could leverage private-sector investments. Stronger stimulation of photonic product development, pilot production, system engineering and product commercialisation is required. Europe has to support SMEs in gaining access to established and emerging markets worldwide, such as USA, China, Russia, India and Brazil. An entrepreneurship for photonic innovations has to be established in Europe at all levels. The challenge for Europe is both to lead in technology, and also to exploit related results through a successful transfer to market. As well as this, these companies still need to access the oxygen for growth necessary for securing their local market and consolidating with other European companies.

Effective standardisation processes for shortening time to market. Research projects provide relevant solutions for their targeted application fields. However, the translation from research to market commercialisation can be a slow and difficult path, which often fails to complete unfortunately. Standardisation is a key for the industrialisation of research solutions, but frequently takes too much time and money, hindering research solutions in reaching a global market. Therefore standardisation processes need to be addressed to achieve simplification and so improve effectiveness.

Fostering synergies along the entire value chain is pivotal for aligning the efforts of all the players involved. As the network evolves to an
Emerging paradigms, such as 'software-defined photonics', underpin the need for consolidation of networks and systems with the underlying photonic components. Increasingly dynamic and flexible eco-system, there is a growing need for smarter and more reconfigurable photonic components. Emerging paradigms, such as 'software-defined photonics', underpin the need for consolidation of networks and systems with the underlying photonic components. Introducing functionality along this trend tends to increase component complexity, which in turn exacerbates the cost of design, fabrication and testing necessary for the development of a new product or technology. To circumvent this challenge, it is necessary to capitalise and invest on existing platforms, such as EUROPRACTICE and FIRE, and to expand other mature and value-adding initiatives, such as ePIXfab, ACTMOST and EUROFOS, into new platforms. The goal here is two-fold: (i) to offer specialised facilities and expertise over the whole range of the value chain, namely from photonic system design and prototyping through to testing, so as to translate R&D results into innovative products, and (ii) to connect the value chain of photonics with other value chains within the ICT ecosystems, such as embedded systems, complementary telecommunication technologies, networks of the future, future Internet, and flagships.

To boost Europe’s competitive advantages, elements of the value creation chain, ranging from research through the building of products, have to be synchronised. In this context, it is proposed that already existing organisations, networks and platforms are embedded into a new streamlined value creation chain through the creation of the following specific European platforms, each characterised by a set of well-defined functions and interfaces:

**EuroLab – European Photonics Laboratory:**
The EuroLab is a federation of academia, research institutes and industry that pool their joint expertise. To cover the whole value chain, there will be networking, systems, and component/subsystems groups. Industrial partners can pose questions and raise study items that are then subsequently investigated by smaller teams. Topics will include forward-looking product ideas, technical feasibility studies, open questions in standards, and research requests to continue feeding the innovation cycle 5 to 10 years ahead. The evaluations will be theoretical, simulations, lab experiments or a mixture. The process for this must be lightweight and must guarantee commercial confidentiality, although it is expected that the majority of results will subsequently be made available publicly, and will also form the basis of on-going technology roadmapping. This can be seen as an evolution of a Network of Excellence, where there is funding for the academic partners to address the study items set by industry partners.

**EuroSaP – European Photonics Specification and Prototyping:** To date, EC projects have comprised largely of precompetitive research carried out by independent parties. While this has helped to build up knowledge (and some IP), commercialisation of the results has been limited, and the results are largely uncoordinated or at best complementary. A mind-set change is required with respect to the focus of these activities: more people from the product side need to be involved, to ensure the necessary upfront agreement on joint product solutions. An industry consortium-driven approach will be necessary to agree such a common framework for future product solutions and to define the specification of the constituting components. Partners across the whole value chain will be involved, from network operators, to system, optical subsystem, component and ASIC vendors. The individual consortium composition will of course be dependent on the specific project. Differentiation is possible by customisation of the components and/or the way in which such solutions would be used in a network/system context. An example of a successful agreement on a worldwide scale is the 100G long-haul multi-source agreement group in the OIF, which has demonstrated the effectiveness of such an approach. EuroSaP will work independently or liaise with other groups (e.g.
ETSIs) in defining such multi-source agreements outside the EU, and, in addition to the specifications, would also be responsible for the implementation with European partners. A successful example of such an implementation is the 100G consortium in Japan, where, under leadership of NTT, all major system and component vendors have jointly developed the necessary components (based on the OIF specification) required for the realisation of 100G coherent interfaces, with substantial funding from the Japanese government. Continuing these collaborative activities, the same consortium is now already working on solutions for 400G. Based on Europe’s strength in the design & manufacturing of photonics and electronics, it is desirable to also adopt a similar approach in Europe, for example in the following breakthrough technologies:

- **Access**: Low-cost tunable SFP+ DWDM transceivers for TWDM-PON and P2P applications
- **Access**: Ultra-compact Nx10G DWDM Tx/Rx arrays for TWDM-PON and P2P applications
- **Backbone**: Ultra-compact Tx/Rx components for 2nd generation 100G coherent transceivers (based on Silicon or InP, integrated RF electronics, common form factor)
- **Backbone**: 1-Tbps software-defined transceivers (array transmitters and receivers with integrated RF electronics at 2–3 times today’s baud rate, Tbps DSP, Tbps OTN framer)
- **Interconnects**: Tbps active optical cable

The developments will be carried out by value chain partners within the consortium, and will make use of EuroFab facilities where indicated. System vendors will then leverage these developments to build system and network solutions, and then test them with carrier partners.

EuroFab – European Photonics Fabrication: This activity deals with photonics fabrication in Europe, and aims at leveraging and extending activities already started in projects such as EuroPIC (covered by Work Group 6 Optical Components and Systems). European research on photonic chips has resulted in many innovative ideas. However, the connection between the chip itself and a component or subsystem that can be used in an optical communication system, often needs strengthening. The packaging of the components, the integration with the necessary RF and control electronics, and the overall integration into a module and subsystem are all critical points for successfully turning a photonic chip design into a commercial product. Specifically for new components, custom drivers and/or control electronics are often not available and may need to be designed, manufactured, and integrated. Assembly technology, and electrical, mechanical and thermal management are critical components that need to be considered in the design flow, and for defining tooling support and partner set. EuroFab will be a network of partners that develops and follows a common design flow, and which can be used for developing large volume, standard products, as well as application specific solutions. Given the fact that some of the disciplines here require very specific knowledge, there is a large opportunity in this area for SMEs, who could offer their services in addressing one or several steps throughout the entire process. Based on the current European fab capabilities, components and subsystems based on silicon, InP and polymer photonics will be the likely focus of this activity.
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EuroTaP – European Photonics Trial and Procurement: This activity aims to foster the early adoption and ramp-up of new innovative technology by creating testbeds for verifying the technologies and experimenting with value added application that can then be delivered over such infrastructures:

- Using public procurement in European research and education networks in order to deploy innovative core network technologies (specifically software-defined optics and software-defined networking control paradigms), and gather first-hand feedback. In the procurement processes of national research and education networks (NRENs), priority will be given to products/vendors with design and manufacturing in Europe. Innovation is anticipated at both the hardware and software levels. Consequently, such testbeds are very suitable for testing capabilities of new software running on innovative new hardware, as well as for bringing early prototype hardware into the field (for example, out of EuroFab and EuroSaP).
- Incentivising fibre build-out in wireless and wired aggregation networks, and combining funding for fibre infrastructure measures with the directive to purchase network equipment, wherever possible, from European manufacturers. Leveraging such network infrastructure to demonstrate new applications and services, and providing a testbed for players to demonstrate IT/Cloud and networking convergence.
- A similar set-up will also be considered for universities to create a testbed for datacentre interconnect and switching technologies; again, a clear preference should be given to products developed/manufactured in Europe.

The proposed timeline for EuroLab, EuroSaP, EuroTaP and EuroFab, as applied to the previously listed backbone technology examples, is illustrated in the following table.

**Major photonics research & innovation challenges**

With respect to photonic networks, the following research and innovation challenges exist:

- Broadband terrestrial backbones. The exponentially growing data consumption in fixed and mobile access puts more and more stress on the core of the network. In fact, based on various traffic measurements and predictions, traffic volume in the core network is expected to grow by roughly a factor of 10 within the next 5 years, and by a factor of 100 within the next 10 years. Peak throughput at core network nodes is expected to reach several 100 Tbps by 2020. Technologies utilised in optical networking are approaching fundamental limits set by physics and information theory, and will therefore require extraordinary research effort to extend further. Several options exist for coping with future capacity demands of the optical core network, for example, increasing baud-rate, constellation size, additional wavelength-bands, flexible grids, or by utilising spatial or mode multiplexing. Electronic functionalities (e.g. A/D converters, regenerators) should be implemented on a photonic basis (e.g. photonic A/D, all-optical regeneration), offering potential cost reductions, increased data rates, and reduced energy consumption. All these options require significant advances in technology, and...
Photonics Research and Innovation Challenges

would probably have to be used together to enable the core network to cope with the predicted traffic demand from the network edge. To achieve transmission rates approaching 1 Tbps per channel, substantial research effort will be required at the component level (efficient, linear and broadband E/O and O/E converters, new fibre types, new optical amplifiers, optical regenerators), on electronics (analogue-to-digital and digital-to-analogue converters, linear amplifiers, power-efficient signal processors), and on processing (signal processing algorithms, advanced coding techniques). Rapid prototyping and test of PICs and their subsystem will be key factors for success.

Optical network and IT convergence. Optical networking is essential for interconnecting datacentres and enabling users to access their content and applications. It may also play an increasing role inside datacentres. Cloud based datacentres have recently absorbed many PC-type applications, such as email, productivity tools, and customer relationship management. These applications are generally considered as requiring low user interactivity. Highly interactive, multi-media PC applications, such as video editing, computer aided design, and games consoles, are also increasingly being moved into the cloud. When computing and data storage is handled largely in remote datacentres, networking
broadband fibre based access: Next-generation optical access networks are foreseen for providing multiple services simultaneously over common network architectures to different types of customers. Access networks capable of interconnecting higher number of users with a symmetrical bandwidth of up to 10 Gbps per customer are required. The aim is to achieve the requested capacity, QoS performance, and latency constraints in the access network, by exploiting the vast available bandwidth. The challenge will be in exploiting the full fibre bandwidth to create a hierarchically-flat access network. Additionally, there is a technical challenge concerned with the possibility of ultra-long-reach access performance, that is, ‘unregenerated’ transportation of the multiple data channels over long distances. Future long-reach access networks will consolidate the metro-access network structure, especially by reducing the number of required central offices that subscribers are connected to. The development of truly cost-effective integrated components and sub-systems with low power consumption is required for the high-speed optical access network. This must support the specific requirements, such as low latency, for extended wireless features like Collaborative Multi-Point (COMP) operation, and self-optimisation and topology control have to be addressed. Furthermore, optical access networks will play an important role when so-called cloud based radio access network (C-RAN) architectures are rolled out. Increasing demand for spectral efficiency and operation of mobile wireless access in more and more bands requires an increasingly higher number of deployed wireless access nodes, capable of supporting multiband wireless access and increasingly more cooperative features. For the sake of flexibility and more future-proof deployment of fibre infrastructure, it is expected that next generation fibre access networks for mobile front- and back-haul must support heterogeneous transport of digital (and digitised) signals to and from wireless access points, including aggregation and routing, thereby starting a new era of mutualisation and convergence of fixed and mobile networks.

Optical interconnects lighting the datacentre: New broadband applications are transforming the Internet into a content-centric network, fuelling the proliferation of datacentres. The new trend of warehouse-scale datacentre computing is raising the bar for high-speed interconnection, requiring unprecedented information densities and link counts, whilst simultaneously causing the energy requirements of a typical server farm to surge. The use of parallel optics for rack-to-rack communication has proven decisive for current systems, but is not enough for sustaining performance enhancements and containing energy consumption. Low-energy photonic solutions have to penetrate at all levels of the interconnect hierarchy, from rack-to-rack and board-to-board, to chip-to-chip and intra-chip data links, in order to accommodate the traffic and avoid an explosion in energy consumption. Following current proof-of-principle demonstrations, the focus will be towards low-cost technologies capable of overcoming the cost barrier for massive adoption. Addressing diverse application scenarios, with transmission distances ranging from a few mm in the case of on-chip interconnects and reaching up to 2 km for campus networks, presents a very broad set of challenges, and necessitates the development of tailored technology solutions for each application. In this context,
2. Photonics Research and Innovation Challenges

Performance enhancement would be achieved in each case through an appropriate mix of disciplines, such as the upgrade of channel rate or the introduction of additional degrees of parallelisation (wavelength- and space-multiplexing or multi-level modulation). Effective integration of optics at all levels of interconnects demands a holistic design approach for the entire system (processor, server, datacentre), so as to ensure optimal use of system resources and maximise power efficiency.

In general, innovation will be required:
To make optical networks more transparent and secure. By removing unnecessary optical-electrical-optical conversions in aggregation nodes, routers and switches, whilst managing the resulting increase in heterogeneity in fibre types and network architectures. By allowing several bit-rates, modulation formats, and radio standards to travel across the same generic infrastructure, enabling future-proof and cost-effective convergence of mobile and fixed, metro and access networks. By providing optical layer security to enable secure exchange of data in the network on the lowest possible layer.

To make optical networks more dynamic and cognitive. By introducing true flexibility in photonic networks through fast-established circuits or optical packets, coping with varying traffic demands, benefiting from flexibility and elasticity in format, channel spacing or bit-rate. This while reducing latency, and managing quality of service at the photonic layer, so achieving autonomous operation of photonic network elements, including self-diagnosis, restoration and optimisation with efficient use of monitoring and adaptation capabilities.

To make optical networks faster. By deploying a disruptive mix of technologies to match the predicted capacity growth of a typical 1 Gbps per user in wireless access by 2020, to a typical 10 Gbps per user in wired access and to a typical 1 Tbps per channel in the core. This involves coherent detection with intelligent digital signal processing, exploiting all modulation spaces and multiplexing schemes, thereby increasing spectral efficiency, whilst expanding the bandwidth of optical amplifiers and improving their noise properties.

To make optical networks greener. By expanding the role of photonics from core down to home access, and promoting optical bypassing whenever possible. By turning all photonic equipment to idle mode when possible, and performing power-efficient all-optical switching and processing as appropriate. By simplifying or removing unnecessary protocols, and performing energy-aware optical routing to reduce cost per transmitted and routed bit.

To bring optical networks closer to the customer. By ensuring high-bandwidth, mobile, fast, green, secure, and reliable customer services by optical wired and wireless home and in-building networks.

**Expected impact for Europe**

In most countries information and communication technology infrastructure is now considered to be a critical part of its national infrastructure and the key to future economic growth. The ICT sector is directly responsible for 5% of Europe’s gross domestic product, with an annual market value of €660 billion. As an enabler, ICT plays a vital role in enhancing other sectors’ business growth. According to the Photonics21 study *The Leverage Effect of Photonics Technologies: the European Perspective*, photonic technologies leverage a telecommunication infrastructure market of €350 billion and impact more than 700,000 jobs in Europe (2010).

Broadband has the power to spur economic growth by creating efficiency for society, businesses and consumers. Both broadband availability and transmission speed are strong drivers in an economy.
Doubling the broadband speed for an economy increases GDP by 0.3%, which is equivalent to $126 billion in the OECD region. This growth stems from a combination of direct, indirect and induced effects. Direct and indirect effects provide a short to medium term stimulus to the economy. The induced effect, which includes the creation of new services and businesses, is the most sustainable dimension, and could represent as much as one third of the mentioned GDP growth. If broadband

Roadmap for 2014–2020

<table>
<thead>
<tr>
<th>Broadband terrestrial backbones and datacentre hosted cloud applications</th>
<th>Pre-Horizon 2020</th>
<th>2014/2015</th>
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<tbody>
<tr>
<td>Applied research on broadband terrestrial backbone systems to increase overall system and network performance, funded in national and EU projects, e.g.: SaSER focusing on save and secure routing. IDEALIST focusing on transport systems enabling flexible transmission and switching of 400 Gbps and beyond per channel. ASTRON focusing on adaptive software defined terabit transceivers. GALACTICO focusing on TbE integrated coherent transmitters and receivers.</td>
<td>Development of further concepts to increase overall network performance with respect to capacity, speed, power consumption, security and flexibility with the focus on: Concepts for a next generation of 100/400 Gbps transponders with lower power consumption, smaller form factor, and lower cost Concepts for system architectures to deliver up to 1 Tbps per channel and up to 1 Pbps per fibre in the core/metro network Concepts for contention-less ROADMs capable to handle Tbps-signals in a flexi-grid environment New concepts for elastic bandwidth allocation, switching and resource defragmentation; concepts for virtualisation of network resources Software-defined network control, approaches towards cognitive and self-managed optical networks, solutions for network programmability on application level Value creation through extended field tests with completed 400 Gbps systems in National Research and Education Networks (NREN). Ramp-up of system and device production.</td>
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</table>
2. Photonics Research and Innovation Challenges

Indirect effects, such as spillovers to other industrial sectors, are initiated on a longer time scale, 10 to 20 years, and result in an efficiency improvement of the economy. Connectivity and broadband are just a starting point for new ways of innovating, collaborating and socialising.

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<tr>
<th>2016/2017</th>
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<tbody>
<tr>
<td>Development of highly integrated sub-system solutions for Tb/s signal generation, transmission, routing, detection, and processing:</td>
<td>System design, integration and verification for selected high-impact applications:</td>
<td>Deployment in European NRENs. Transfer to volume production.</td>
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<tr>
<td>- Tb/s SDO components based on Silicon/InP</td>
<td>- Demonstration of flexible Pbps core/metro networks using elastic bandwidth allocation and resource virtualisation</td>
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<tr>
<td>- Enhanced digital signal processing units, FEC solutions, coded modulation</td>
<td>- Demonstration of OpenFlow controlled networking for datacentre hosted cloud applications connected to Pbps optical transport systems</td>
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<tr>
<td>- High-speed optical-to-electrical and electrical-to-optical interfaces with low power consumption at low cost jointly integrated with high-speed pre- and post-processing DSP units</td>
<td>Building up user groups and competence networks to demonstrate, evaluate and promote the selected high-impact applications.</td>
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<td>- Software-defined transceivers</td>
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<td>- Low noise optical amplifiers and regenerators</td>
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<td>- Robust excitation units for few-mode- and multicore fibres</td>
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<td>- Contention-less flex-grid ROADMs</td>
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<td>Applied research with the focus on broadband fibre based access and in-building networks, funded in national and EU projects, e.g.: <strong>OCEAN</strong> focusing on &gt;20 Gbps OOFDM based access. <strong>OTONES</strong> focusing on OFDM-PON with colourless transceivers. <strong>CRITICAL</strong> focusing on 1 Gbps+ coherent access systems with DSP. <strong>TUCAN</strong> focusing on low cost tunable transceiver technology. <strong>OPTAIN</strong> focusing on LTE backhauling. <strong>FIT</strong> focusing on the gateway functionality to central office and home area networks. <strong>C3PO</strong> focusing on colourless and energy efficient optical components for future access.</td>
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<td>Novel concepts for an integration of optical switched network architectures and cloud server technologies and their associated control and data planes into a singular architectural object. Proof of concepts in lab experiments to derive required device and system specifications.</td>
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<th>Broadband fibre based access and in-building networks</th>
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<tr>
<td>System demonstrations of on-going research initiatives serving as a catalyst to new concepts to increase overall network performance with respect to capacity, speed, power consumption, security and flexibility to deliver 10 Gbps+ to the user in metro/access and 1 Gbps+ in in-building networks with the focus on: ▪ Convergence of wire-line and wireless access network technologies ▪ Convergence of access/metro/core network technologies ▪ Networking-assisted virtualisation and pooling of IT appliances for security, bandwidth and content ▪ Cloud based access services ▪ Dynamic optimisation of Quality of Experience by orchestration of networking and content delivery</td>
<td>Value creation through early field tests.</td>
<td>Value creation through extended field tests with completed systems in smart city environments.</td>
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## 2. Photonics Research and Innovation Challenges

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- Demonstration of flexible Pbps core/metro networks using elastic bandwidth allocation and resource virtualisation  
- Demonstration of OpenFlow controlled networking for datacentre hosted cloud applications connected to Pbps optical transport systems  
Building up user groups and competence networks to demonstrate, evaluate and promote the selected high-impact applications. | Deployment in European NRENs. Transfer to volume production. |
| Development of highly integrated sub-system solutions for next generation optical access architectures focusing on:  
- Low-cost SFP+ tunable transceivers  
- N×10G Tx/Rx DWDM arrays at low cost  
- High-speed optical-to-electrical and electrical-to-optical interfaces with low power consumption at low cost jointly integrated with high-speed equalisation (e.g. DSP, equaliser) units  
- Silicon/InP hybrid integrated circuits; 3D integrated devices; Introduction of polymer materials towards cost effectiveness and low power consumption  
- Visible light communication and navigation, integrated solutions for lighting and communication  
Dedicated prototyping of devices and sub-systems. | | |
Towards 2020 – Photonics driving economic growth in Europe

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<td>Applied research on optical interconnects to increase device and system performance, funded in national and EU projects, e.g.: <strong>SEPIANet</strong> focusing on optical coupling techniques for chip to PCB, optical board-to-board interconnects and pluggable optical PCB connectors. <strong>PLATON</strong> focusing on the demonstration of a Tbps silicon-plasmonic router for optical interconnects. <strong>MIRAGE</strong> focusing on Terabit board-to-board and rack-to-rack parallel optics. <strong>PHOXTROT</strong> focusing on photonics for high-performance, low-cost and low-energy data centres and high performance computing systems. <strong>POLYSYS</strong> focusing on a disruptive capacity upgrade in data centres using a polymer integration technology. <strong>PLAT4M</strong> that focuses to bring existing silicon photonics research platforms to a maturity level which enables seamless transition to industry.</td>
<td>Proof of concepts in lab experiments to derive required device and system specifications. Ramp-up of system and device production at low cost for 1 Gbps+ per subscriber.</td>
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<th>Optical interconnects lighting the datacentre</th>
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| Penetration of the optical technology to the whole datacentre/HPC eco-system and in all interconnection layers:  
  - Optical networks on chip  
  - Optical on-board interconnections  
  - Optical backplanes  
  - Active optical cables exploiting advanced modulation formats  
  - Data transfer architectures to accommodate datacentre topologies and server inter-connections  
  - Exa-FLOP high-performance computing and Zetta-byte storage | Proof of concepts in lab experiments to derive required device and system specifications. Value creation through launching of products and transfer to volume production. |

Building up common test equipment and platforms for tests at device and (sub-) system level. Value creation through early field tests. Development of integrated solutions for optical interconnection concepts with the focus on:  
  - Multi-layer optical PCBs  
  - Single-mode PCB solutions for on-board and board-to-board interconnections  
  - New interfacing approaches to facilitate the interconnection of various interconnection layers  
  - Exploitation of Silicon and Polymer integration technologies to achieve low cost and low power consumption  
  - 3D-integrated devices  
  - Active optical cables  

Dedicated prototyping of devices and sub-systems. Building up common test equipment and platforms for tests at device and (sub-) system level. Value creation through early field tests. System design, integration and verification the demonstration of an optically inter-connected datacentre including:  
  - Networks on a chip  
  - On-board interconnects  
  - Optical backplanes  
  - Active optical cables  

Building up user groups and competence networks to demonstrate, evaluate and promote the selected high-impact applications. Deployment in European NRENs. Transfer to volume production.
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Towards 2020 – Photonics driving economic growth in Europe

New mass markets will be created. For example, in health care alone it is expected that 500 million people will use mobile applications. With speed requirements steadily increasing, photonic communication is mandatory for delivering broadband services to end users, either directly as optical fibre access, or indirectly as optical feeder technology to copper or radio access networks. Photonic communication technology is the key enabler for a future-proof way of living, allowing home working and learning, e-health and e-government, and other e-services.

The steadily rising cost of energy and the need to reduce global greenhouse gas emissions have resulted in energy becoming one of the primary technological challenges of our time. ICT in general, and optical technologies in particular, are expected to play a major role in the reduction of the worldwide energy requirements. Indeed, recent studies show that ICT is today responsible for about 4% of the world energy consumption, a percentage expected to double over the next decade. Optical networking plays a key role in the support of energy efficient and hence sustainable future ICT solutions. The achievable level of energy efficiency will be very much dependent on the specific architectural approaches that are adopted, the technology choices that are made, and on the use of suitable planning/routing algorithms and service provisioning schemes. In this context, it is also important to design and operate optical networks taking full consideration of the details of the services and applications that they will support, as well as the end devices they will interconnect. Attempts to match the characteristics of currently popular applications, such as P2P, grid or cloud services, to the underlying optical-based network infrastructure can further enhance energy savings for operators, service providers and users.

Optical ICT technologies will play a major role in the reduction of worldwide energy requirements.
2. Photonics Research and Innovation Challenges

2.2 Industrial Manufacturing & Quality

Main socio-economic challenges addressed

Photonics is already a strategic capability for European industry and a key enabling technology for manufacturing processes, and will become even more so in future. With the ‘laser light’ tool, manufacturing processes can be handled automatically and flexibly, producing components and products of extraordinary quality, and in a much ‘greener’ way in comparison to most other energy sources.

The trend towards customisation and the growing importance of industrial design, as observed most notably in consumer electronics, will require novel methods for proving new product properties and shapes, and bespoke production capabilities. The inherent flexibility of the laser tool makes it the ideal choice for meeting these requirements. Further advantages of the laser as a working tool are that it does not wear out, it allows the integration of monitoring and control systems based on intelligent photonic sensing techniques, and it allows zero-fault production, even in single part production.

The extreme precision with which laser energy can be applied results in a substantial reduction in the total energy consumption, when compared to standard production processes. This makes laser processing an increasingly relevant technology for a future sustainable economy in Europe. The ability of the laser to machine materials that are otherwise very difficult to process with conventional tools makes it an ideal tool for fabricating lightweight, high-strength constructions, such as crash-safe car bodies or wind turbine blades. Furthermore, the laser itself will play a major role in facilitating green manufacturing, since laser processes allow for very precise, well-controlled and therefore highly efficient energy deposition on the work piece. A further environmental attraction of laser-based processes is the reduced consumption of chemicals, for example, by replacing the chemical etching baths currently used for the manufacturing of rotogravure cylinders by a laser engraving process. Innovative laser processes will increase the efficiency of photovoltaic devices and will enable energy storage devices with higher capacities; a key requirement for future electric cars.

Laser processing is also expected to make a significant contribution in tackling the societal challenge presented by the ageing population in Europe. This will result from the wide range of innovative new products enabled by new photonic manufacturing technologies, including such varied products as pace-makers, synthetic bones, endoscopes, and micro-cameras used for in-vivo health care processes.

Today, photonics is not solely a driver for innovation in manufacturing; the photonic technologies, laser tools and process systems themselves are a worldwide multi billion industry, dominated by European companies. Consequently, in addition to photonics aligning well with sustainable development, green technologies and resource-efficient production, it also contributes significantly to employment.
The world market for laser systems in 2011 was approximately €7b with Europe taking a third of this. In specific sectors, such as in Lithographic Production Technologies, this share is higher than 50%. However, overall the European market share of this sector has declined from its 2008 value of 39%, as a result of growing competition from East Asia. Investment in developing new technologies will be essential to reverse this decline.

In addition to the direct market for laser systems themselves, use of laser processes provides significant competitive advantage to manufacturing industries, such as the European car industry, thereby greatly leveraging the economic benefits.

**Major photonics needs**

The major photonics need is to broaden the spectrum of applications of laser production technologies, especially so in light of the increasing demand for energy and resource efficient products. This applies to all sectors where laser technology can offer new production solutions, new product qualities, and cost benefits. Key opportunities for this include energy conversion, electronics, hybrid materials, lightweight construction, mass customisation and rapid manufacturing, print technology, and product marking.

**Involvement of value chain partners**

Photonics is a cross-sector technology, and Europe-wide cooperation along the entire value chain will be essential for future progress and success. All the relevant players need to be involved in R&D projects, research networks and clusters, providing the scientific and innovative solutions to manufacturing problems.

The physical and technical limitations of today’s optical components can only be overcome through interdisciplinary research efforts in manufacturing technologies, microsystem engineering, nanotechnology, telecommunications, and optics. More fundamental limitations must be tackled by basic research on the interaction between light and matter, on novel materials, and on new structures with revolutionary photonic properties. This will require work in materials science, quantum optics, thermodynamics and solid-state physics.

New opportunities for design and manufacturing will require highly qualified personnel at all levels. Demand for skilled staff will continue to increase, and special efforts in education and training will be necessary to meet this demand. The creativity of skilled individuals will be a key factor in ensuring innovation and maintaining Europe’s leading position in photonics manufacturing.
Major photonics research and innovation challenges

Europe has a world-leading position in the market of photonics for industrial production, with the world’s largest laser companies and manufacturers of key laser components located in this region. Europe’s laser technology leads in terms of innovation and optical excellence when compared to other regions. To ensure that this competitive edge is maintained, the principal research and engineering efforts have to focus on more efficient lasers (more light output for a given energy input), longer-lasting components that can be recycled, and maintenance-free manufacturing equipment. The markets for new processing strategies and new photon transmission systems must also be addressed. The most challenging problem in laser source manufacturing is price pressure, a result of the increasing cost competition exerted mainly by Asian manufacturers.

The primary research areas to be addressed will need to cover all stages of the manufacturing process, from basic research and development through to the products themselves and their market penetration.

The goal is to extend laser processing capabilities significantly beyond their current position, and thus allow many new and challenging processing applications to be addressed. For example:

- processing of composites and dissimilar materials
- basic research on material processing and applications (e.g. composites)
- additive manufacturing (e.g. ‘product printing machines’ based on the selective laser melting [SLM] process)
- mass production of individual items
- colour marking
- fabrication and laser treatment of functional surfaces and advanced materials (biocompatible functional implants, nanoparticles, fibres for microelectronics, photovoltaics, flat-panel displays, laser cleaning, surface hardening, and bonding of transparent materials)

To achieve this goal, advances are necessary in both the underlying laser technology itself and the processes though which they are deployed. In terms of these laser sources and optical components, the focus has to be set on reliable, reproducible and precise methods for automated assembly of photonic devices and lasers, with improved performance in terms of power, beam properties, efficiency and size, as well as better spatial & temporal control and stability - and all at lower cost. A further key requirement will be the incorporation of adaptive reconfigurable beam delivery networks, capable of high power and intensity. New applications are expected, for example through the use of ultra-short laser pulses. However, to take full advantage of such new laser sources, new high-speed beam deflection technology also needs to be developed in parallel. These improvements will be crucial for extending laser technology to large market sectors, such as electronic industries or mass customisation of consumer goods.

Europe’s laser technology leads the world in terms of innovation and optical excellence.

Principal research and engineering efforts must focus on more efficient lasers, longer-lasting recyclable components, and maintenance-free manufacturing equipment.

Lasers enhance manufacturing processes. © Fotolia
Therefore, more efficient lasers and new photonic components will be needed, including:

- high brilliance diode lasers (output power >20W per emitter) with improved energy efficiency and beam quality
- ultra high power (>1kW), ultra short pulse (fs-ps), visible and near IR lasers
- highly efficient and long term stable UV/EUV lasers (solid state)
- cw UV direct imaging (with 100W)
- ‘fully tunable’ laser (pulse width tailored to the application and variable in wavelength – UV to visible to MIR)
- efficient mid-infrared laser with output power up to 1kW (e.g. 1.5–1.9 µm / 2.6–4 µm for organic materials/polymers)
- industrial MIR systems
- coatings and components (e.g. gratings, isolators) for high power/high intensity beams
- non-linear transparent materials (crystals, ceramics) for high power/high intensities (and short/UV wavelengths)
- fast modulation capability provided in conjunction with high speed scanning devices (for synchronisation)

In the drive for higher product quality, further development and production implementation will be needed for beam delivery and control, process monitoring, adaptive control of the laser manufacturing process, and quality inspection of laser manufactured goods. Aspects of integrating laser sources within machine tools, in particular robotic manufacturing tools, will also require optimisation and standardisation. This will require that the following technological challenges be addressed for beam delivery, shaping and deflection systems:

- remote technologies
- connectors and integrated beam switches
- monitored high power connectors
- diffraction limited fibre delivery of output power >1kW over a distance of 100m
- laser arrays, multiple fibre arrays, and fibres for transport of ultra-short/energetic pulses
- precise beam deflection with a target speed of 1km/s (at the work piece)
- dynamically reconfigurable intensity distributions for advanced thermal management of laser processes e.g. for welding or soldering
- new electro optic materials, beam delivery systems, and fast electronics and data processing
- standardised modular systems
Whilst for achieving the necessary improvements in quality control and sensors, the following challenges must be addressed:

- process monitoring sensors
- multi-spectral imaging sensors
- real-time process control for Fully Automated Installation (FAI) applications
- the combination of laser technology with online non-destructive testing
- multi-spectral imaging and focusing optics for simultaneous processing and observing (coaxial process control)

These advanced laser processing capabilities will also open the way to ground breaking new optical components and the corresponding technologies for their fabrication. Further, when combined with the results of accompanying fundamental work in laser beam/material interactions and process control, exciting new photonic processes for manufacturing will be achievable, offering more flexibility, more functionality and greater productivity. Such innovative components and processes are the key to realising this vision of strengthening and sustaining Europe's leading position on the world market for photonic technologies and mechanical engineering.

Expected impact for Europe

Lasers represent a versatile tool for handling a wide range of manufacturing tasks all along the workflow chain, from material processing through to quality control. Typically the added value generated with a machine tool or a laser system, calculated as a multiple of the cost of the tool itself. Taking due account of this factor, the laser processing industry on its own is a multi-billion Euro industry, and it also has a substantial leverage effect on many other industries, most notably in the European automotive sector.

In addition to the clear economic benefits for Europe, the impact of the next generation laser sources and photonic manufacturing processes on today's most challenging societal questions will be high. Three specific examples are:

- Sustainable (Green) Economy: Light weight cars, batteries and fuel cells, high-efficiency photovoltaic modules, to name but a few, all require laser technology for their production. An additional key benefit of using laser processing technology for green manufacturing is that lasers reduce energy consumption and chemical waste.

- Ageing Society: From pace-makers to synthetic bones, and from endoscopes to the micro-cameras used in in-vivo processes – laser technology plays a major role in addressing the needs of our ageing society.

- Information Technology: Laser-powered, extreme UV-light sources will provide the critical manufacturing tool essential for achieving future miniaturisation and cost reduction of microelectronics.

In terms of the competitiveness of European industries, the proposed research priorities will have a major impact on maintaining the established industrial leadership of laser and laser processing technologies in Europe. They will therefore have a direct and positive influence on the future advanced, laser-based manufacturing technology in Europe. Additionally, they will broaden the base of European manufacturing technology, thereby overcoming current disparities and ultimately sustaining economic strength.
**Roadmap for 2014–2020**

<table>
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<tr>
<th>Technological challenges</th>
<th>Research actions</th>
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<th>Cross-cutting Key Enabling Technologies (KET) issues</th>
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<td>Efficient lasers and devices</td>
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<td>Large size precision optic</td>
<td>Greener products: less chemical processing, less energy consumption</td>
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<td>Quality control</td>
<td>Coatings and components for high power/high intensity beams</td>
<td>Laser/motion synchronisation at high repetition rates</td>
<td>New surfaces/materials with impact on: energy, medical, electronics/semiconductor, lightning and manufacturing technologies</td>
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<td>Beam delivery, shaping and deflection systems</td>
<td>Non-linear transparent materials for high power/high intensities</td>
<td>Surface processing with &lt;1 €/m² (cost of ownership)</td>
<td>New products with impact on bio tech, medicine, nano tech, advanced manufacturing</td>
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<td>Ultra-short pulse high power lasers with high repetition rate (NIR, VIS)</td>
<td>Highly individualised products in mass markets (transportation, medical, consumer)</td>
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<td>Fast modulation capability with synchronised high speed scanning devices</td>
<td>Broad scaling range: macro–micro–nano</td>
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<td>Flexible lasers (multi-color, UV-VIS-NIR-MIR)</td>
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2.3 Life Science & Health

Main socio-economic challenges addressed

Progress in the field of photonic methods and techniques for Health and Life Sciences will contribute significantly to solving several of the ‘grand challenges’ of our time as defined in the Lund Declaration of July 2009, by offering “sustainable solutions in areas such as … water and food, ageing societies, public health, pandemics …”.

For most European countries, the projected demographic changes will have drastic consequences for European citizens and their healthcare systems. For example, the number of people older than 65 years will double by 2030, leading to a dramatic growth of age-related diseases including Alzheimer’s disease, cardiac infarction, stroke, age related macular degeneration, diabetes, kidney failure, osteoarthritis, and cancer. Greater mobility of the population will result in the increased occurrence of pandemics. Therefore, providing adequate health care for all European citizens will require enormous efforts. These challenges can best be met through breakthroughs in and deployment of Biophotonic technologies, yielding new cost-effective methods for improved diagnosis and therapy. These same technologies can also serve to control water and food quality, thereby reducing diseases caused by contamination.

Major photonics needs

A major step towards tackling these challenges will be to focus Biophotonics research and innovation on the development of easy-to-access, minimally invasive, low-cost screening methods. These will be based on photonics point-of-care methods and technologies, providing a risk assessment of age and life-style related diseases (ideally risks factors for a combination of several diseases would be assessed simultaneously), thus establishing a reliable result within minutes.

Detailed investigation, employing more advanced diagnostic methods to locate and precisely evaluate the origin of the disease, would then be undertaken if the screening returned a positive result for one of the disease parameters. Improved diagnostic and interventional methods will be developed, based on improved multi-band (X-ray, Ultraviolet, Visible, Near/Mid/Far IR, Terahertz) photonics, spectroscopic and endoscopic devices. These should provide more reliable and precise examinations than current ‘gold standard’ methods, without increasing examination costs or duration. An illustrative example is provided by the diagnosis of bowel cancer, where the established procedure (white-light colonoscopy) is neither precise nor sensitive enough to detect all cancerous lesions, and is considered too invasive a screening tool for the majority of the population. Improved screening should therefore indicate where further diagnostics was necessary, and improved diagnostics could precisely locate and analyse the disease, before therapeutic measures were initiated. These could incorporate multi-band photonics techniques to provide safer, personalised treatment methods, tailored for specific therapy and treatment monitoring.

In addition to their use for the diagnosis and treatment of diseases, multi-band photonics methods could also provide preventative tools, for example, offering analytical methods to monitor and evalu-
ate water and food with regard to quality and potential microbial contaminations. The methods that would be employed for this could be essentially the same as used for advanced screening, perhaps with minor adaptations for the specific target. There is considerable synergy with the sensing requirements for Work Group 5 Security: Metrology and Sensors, and it is therefore anticipated that there will be common solutions, making close collaboration in this field highly beneficial.

**Involvement of value chain partners**

Biophotonics in itself is already a highly multidisciplinary field, involving physicists, chemists, and engineers as method and technology developers, as well as end-users from the fields of biology and medicine. To some degree, industry already reflects this diversity, comprising component and system developers, as well as full solution providers. Over the last few years, component developers have shown a growing awareness of the increasing importance of Biophotonics, and this has been reflected in the growing level of revenues generated in this field. The frontiers between system developers and full solution providers often become blurred, particularly with the growing realisation that the end-users of Biophotonic technologies generally prefer purchasing everything from a single source. Since most of the Biophotonic technologies and methods are, with the exception of conventional microscopes or current X-ray machines, still relatively new, the leading medical device manufacturers have to date shown relatively little interest, and so have limited market presence in this sector. A major breakthrough for Biophotonics in the medical devices market would require a significant increase in the involvement of these companies. Similarly, the early and substantial involvement of the potential end-users, especially that of physicians and clinicians, at all stages of development will be of utmost importance. The involvement of end-users will be critical for the development of solutions tailored to fit their specific needs. Such direct involvement will greatly help maximise the integration of new tools and techniques within the established process flow employed in the clinical environment. The involvement of end-users is generally not an easy task, especially for clinicians, as their steadily increasing burden limits the time available, and their focus on patient welfare tends to result in a relatively conservative attitude to new approaches. This activity would be strengthened by extending the ongoing collaboration with the Nanomedicine European Technology Platform (ETP), though additional measures would also be
essential for reaching out further into the medical world. Additionally, it will be vital to connect with the medical insurance companies to identify and implement opportunities for public procurement. This will lead to precise, reliable, gentle and user-friendly multi-band photonics and spectroscopic methods, widely deployed in clinics, doctors’ practices, and other locations where they provide added value. For addressing food and water quality and safety, connections to the ETP Food for Life, the ETP Global Animal Health, and the ETP Water Supply and Sanitation would be greatly advantageous.

Major photonics research & innovation challenges

In preparation of the second Photonics21 strategic research agenda, Work Group 3 made an evaluation of the different application areas within Biophotonics to establish where unfulfilled but pressing needs existed, and where the employment of multi-band photonics and spectroscopic methods could really make a difference. As a result, five specific areas of health-related application fields were identified as being particularly important and promising, supplemented by further applications in the fields of the environment, food quality and security.

Preclinical research: Although many multi-band photonic and spectroscopic methods could already be deployed today for the benefit of the patient, the ultimate goal of preclinical research is to understand the origin and progress of a disease, from the organ and tissue down to a cellular or even molecular level. This knowledge would allow detecting, curing or even preventing diseases long before the onset of macroscopic symptoms. The prerequisite for gaining such a holistic understanding of life processes are tools and methods that allow seamless observation from the macro- through the micro- and down to the nano-level, without changing or disturbing these processes. The observation should be possible with high resolution and in three dimensions, as well as with sufficient time resolution to reveal fast processes.

Oncology: Cancer belongs to the group of diseases whose incidence rates often increase with age, and it is therefore one of the fastest growing threats to people’s health, especially in Europe. The 5-year survival rate drops rapidly if cancer is not detected before its later stages, therefore early detection is of paramount importance. Unfortunately, for many forms of cancer, screening is either not possible, ineffective or unpleasant (such as colonoscopy). Today’s methods of detection often lack sufficient specificity or sensitivity for the consistently early and conclusive detection of cancer. Then,
even when a cancer has been detected correctly, determining its physical extent for subsequent removal frequently presents a major challenge. A two-step procedure is envisaged for screening citizens for a range of different cancers. In the first step, photonic (or a combination of photonic and non-photonic modalities, such as ultrasound and magnetic resonance) point-of-care technology would be applied to provide a low cost, rapid and reliable risk assessment for a particular cancer or combination of cancers. If the result of this screening indicates risks, advanced and improved analytic (multi-band photonic/spectroscopic) methods, developed for locating and analysing the cancer in a sufficiently reliable and precise way, will be applied. It is likely that these techniques will make use of label-free methods, since the time needed for development of a tool such as an endoscope is usually much shorter than the period necessary to get safety approval of labels for in vivo applications. The techniques could, if advantageous, also employ a combination of photonic and non-photonic technologies, such as ultrasound, magnetic resonance or nuclear scanners. The same techniques or combinations thereof, employed for localising and identifying a tumor, might also be applied in an surgical microscope or in an endoscope for determining the physical extent of degenerated tissue with unprecedented precision, and thus allow the complete removal of this tissue. In cases where removal is not possible, for example, in the case of large area distributed lesions, as can occur for skin cancer, highly targeted treatments based on light, possibly in combination with other effective self-targeting therapeutic approaches, may provide the means for selectively eliminating cancerous tissue.

Infectious diseases: Often the outcome in the case of infectious diseases can be highly dependent on the time interval between onset of infection and administration of therapeutic agents. This is particularly true for sepsis, which is still one of the most underestimated but life-threatening diseases occurring in the clinical practice. Ideally, a suitable therapeutic agent should be administered within one hour after the occurrence of a septic shock. Sepsis can be caused by a wide range of bacteria, as well as by fungi and viruses, so it is of vital importance to identify the specific pathogen responsible. Conventional techniques like cultivation and even new techniques based on polymerase chain reactions (PCR) are often too slow or not sufficiently reliable. These techniques need to be replaced by methods that are really capable of making a difference. Similar techniques, as envisioned for use in screening, will also have the potential to reliably identify pathogens, determine potential antibacterial resistances, and evaluate the host’s immune response. This will enable the administration of targeted agents, avoiding the use of broad-spectrum antibiotics that could facilitate antibacterial resistance. If resistant bacteria are encountered, targeted photodynamic therapies offer a potential solution, especially since their mode of action does not promote resistances. Photonic technologies can also be employed for treatment monitoring (for example, for infectious diseases or cancer therapy) to measure progress and identify necessary treatment modifications, as well as monitoring of the local environment and food to prevent the outbreak of infections (for example, food poisoning from Staphylococcus aureus, described below). Ultimately, very cheap photonic monitoring devices could even be incorporated directly into bandages, infusion sets, etc..

Ophthalmology: Although the eye itself is a tissue affected by age-related diseases, such as retinopathy or geriatric macular degeneration, it can also provide a so-called ‘diagnostic window’ to the body, offering easy and minimally-invasive access to key parameters identified with cardiovascular diseases, diabetes or Alzheimer’s disease. The eye can provide a ‘diagnostic window’ to the body, offering easy and minimally-invasive access to key parameters identified with cardiovascular diseases, diabetes or Alzheimer’s disease.
Therefore the challenge in this field consists of developing optical and spectroscopic techniques and tools that can be applied in a (pre)clinical environment. These would be used in combination with already existing modalities focusing on morphology, such as optical coherence tomography, to investigate the functional and metabolic state of the eye.

**Neuro-monitoring and imaging:** Photonics based tools provide unique contrast for in vivo imaging, and access to key physiological parameters for neuro-monitoring and imaging. In particular, these technologies enable researchers and, increasingly, clinicians, to measure parameters such as cerebral hemoglobin oxygenation, hemoglobin concentration, blood volume, blood flow and oxidative metabolism. Photonics technologies are, by their nature, non- or minimally-invasive, harmless, continuous, portable, inexpensive, and are therefore very well suited to a clinical environment. They are used to monitor the human brain, from neonatal to adult populations, in various applications, ranging from the understanding and management of preterm birth related pathophysiology of the brain, to the management of conditions such as stroke and traumatic brain injury in adults. Photonics technologies can also help to understand the mechanisms of a disease, for example, neurovascular coupling in Alzheimer’s disease. In addition, photonic techniques can help during rehabilitation of brain-injured patients and track brain plasticity. Furthermore, being safe and relatively inexpensive methods, they could be utilised to study large, healthy populations to better understand the effects of healthy ageing and brain development. A major challenge is to bring these technologies to the level of maturity needed for clinical application. This requires improvements in signal-to-noise, usability, major reductions in size and cost, standardisation (both of the hardware and associated software algorithms), validation in real settings, integration with other imaging modalities, and expansion for other biomarkers of these diseases.

**Environmental monitoring, food and drug quality and safety:** Amongst the prerequisites for general health and well being are clean water, air and soil, and safe food, free from chemical pollutants or biological contaminations such as pathogens and their associated metabolism products. The same multi-band photonic and spectroscopic methods and techniques being developed for medical screening applications could, with some modification and adaptations, be employed for monitoring the environment and the quality and safety of food. A recent example of such widespread food poisoning was the 2011 outbreak in Germany, caused by a certain strain of the bacterium Escherichia coli causing a hemolytic-uremic syndrome. In addition, the techniques and methods could also be employed to advance the process analytical technology (PAT) initiative, the aim of which is to allow the in-situ analysis of specific process parameters identified as being critical for drug and food manufacturing, allowing any necessary process adjustments to be applied during manufacture, thereby ensuring quality and efficiency.

**Expected impact for Europe**

It was the optical microscope that first revolutionised our knowledge of the origin of diseases, and provided an instrument not only to detect diseases, but also to find cures for many. Although the diversity of challenges for good health has yet to decrease substantially, the versatile nature of photonics offers enormous and unparalleled potential to meet these challenges, much of which has yet to be fully exploited.
Biophotonics has great potential to mitigate many of the health-related consequences of our ageing society, and thus secure our future health, well-being and mobility, as concluded by the Counsel of the EU on innovation in the medical device sector (2011/C 202/03). A further result of the demographic change is that the elderly dependence factor will increase, meaning that more people aged above 65 will have to be supported by fewer working-age people. As global healthcare expenditures are also expected to grow disproportionately, this means that working-age people will have to bear significantly higher financial burdens. Photonic technologies can help absorb some of these burdens, offering a potential 20% cost reduction\(^5\).

With predictions of double-digit growth, Biophotonics is one of the most vibrant and promising of markets. Increasingly, component manufacturers are addressing this market and aligning their products with the requirements of systems and whole solution providers, thus generating additional synergies. The size of the worldwide healthcare market for optical technologies alone was estimated to be €23 billion in 2010, and to be growing at an 8% CAGR by 2015\(^6\), with substantially large potential leverage effects. Europe’s share of the market currently amounts to about a third. While Europe already has a large share in the microscopy market (>50%), there is scope for significant expansion in the areas of medical imaging and laser therapeutic systems (market share currently ~30%), and especially for in-vitro diagnostic systems (currently below 20%)\(^7\). Therefore, joint efforts and well-directed funding are the correct instruments to strengthen market positions and generate growth and new job opportunities in this important field.

Each year 12 million new cancer cases are detected, a number that is likely to rise steeply over the coming years, as a direct consequence of demographic changes. Correspondingly, the annual number of deaths caused by cancer is likely to increase from 7.6 million in 2007 to 17.5 million in 2050. According to the WHO, early detection could reduce the mortality by 30%, and Biophotonics offers the powerful tools needed for achieving this.

Similar figures apply to most other age-related diseases, such as Alzheimer’s, cardiac infarction, stroke and age-related macular degeneration. For example, recent statistics indicate that cardiovascular diseases, including both ischemic strokes and cardiac infarction, cost the EU approximately €192 billion in 2006, made up of €110 billion for health care costs (about a fifth of the total costs) and €82 billion for lost productivity. Cardiovascular diseases cause 48% of deaths in Europe, and strokes are the second most common cause of death in Europe. In-patient hospital care for stroke victims accounted for about 80% of the total health care costs. We have highlighted this challenge because photonic neuro-monitoring and imaging has tremendous potential for reducing these costs. Other health care issues showing significant increases, which could also be addressed by photonic neuro-monitoring, include traumatic brain injury and Alzheimer’s disease, both of which result in substantial financial and social costs in the EU.

With predictions of double-digit growth, Biophotonics is one of the most vibrant and promising of markets. Increasingly, component manufacturers are addressing this market and aligning their products with the requirements of systems and whole solution providers, thus generating additional synergies. The size of the worldwide healthcare market for optical technologies alone was estimated to be €23 billion in 2010, and to be growing at an 8% CAGR by 2015\(^6\), with substantially large potential leverage effects. Europe’s share of the market currently amounts to about a third. While Europe already has a large share in the microscopy market (>50%), there is scope for significant expansion in the areas of medical imaging and laser therapeutic systems (market share currently ~30%), and especially for in-vitro diagnostic systems (currently below 20%)\(^7\). Therefore, joint efforts and well-directed funding are the correct instruments to strengthen market positions and generate growth and new job opportunities in this important field.

\(^5\) Photonics21 Strategic Research Agenda Lighting the way ahead, page 110

\(^6\) Photonics21 Strategic Research Agenda Lighting the way ahead, page 94

\(^7\) Optech Consulting, 2007. From the report Photonics in Europe, Economic Impact, published by Photonics 21
## 2. Photonics Research and Innovation Challenges

### Roadmap for 2014–2020

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<tr>
<td>Development of reliable low-cost photonic-based screening methods that allow a fast risk assessment of age and life-style related diseases.</td>
<td>Improved analytic (multi-band photonic/spectroscopic) methods or combination of photonic with non-photonic technologies, which allow further analysis of positively screened persons more reliably and precisely than with current gold standards.</td>
<td>Improved, safer and personalised treatment (therapy and monitoring) based on multi-band photonic techniques and methods or on combinations of photonic and non-photonic modalities.</td>
<td>Next generation analytical (multi-band photonic/spectroscopy based), low-cost and fast methods to control water and food safety/quality.</td>
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### Research actions

(Which solutions should be investigated?)

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<tr>
<th>Photonic based mobile point-of-care devices with high user friendliness and the following specifications:</th>
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<tr>
<td>High sensitivity, specificity and accuracy, with high reliability and speed</td>
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<td>Robustness</td>
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<td>Safe to operate</td>
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<td>Low cost</td>
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<td>Compliant with regulations</td>
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| New and innovative multi-band photonic and spectroscopic imaging methods and devices (including endoscopes) using multimodal approaches, that are either label-free or based on already safety-approved labels to further analyze age and life-style related diseases like cancer, cardiovascular and eye diseases and various neuro-pathologies. |

| Photonics-based highly targeted therapies and continuous monitoring of therapeutic success (also based on other therapeutic approaches). |

| Next generation of Biophotonic methods and tools to understand the origin of diseases. |

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<tr>
<th>Next generation photonic based analytical devices for environmental/food quality and safety applications with the following specifications:</th>
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<tr>
<td>High sensitivity, specificity and accuracy with high reliability and speed</td>
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<td>Robustness</td>
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<td>Safe and easy to operate</td>
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<td>Low cost</td>
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<tr>
<td>Involvement of medical device manufacturers, pharmaceutical industry (PAT initiative) and clinicians is mandatory. Market potential: Aimed at low cost, point-of-care devices that should be made available to all European citizens through clinics, doctor’s practices and even for home-use.</td>
<td>Involvement of medical device manufacturers and clinicians is mandatory. Market potential: The devices are aimed at an employment in clinics and in doctor’s practices at costs that are comparable to today’s equipment.</td>
<td>Involvement of medical device manufacturers and clinicians is mandatory. Market potential: The techniques and devices are aimed for an employment in clinics.</td>
<td>Involvement of public procurer (e.g. public institutes responsible for environment and food safety). Market potential: Aimed at low cost and mobility, the devices should find broad and universal applicability.</td>
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<tbody>
<tr>
<td>Pilot action for mobile point-of-care screening devices together with KET ‘Nanotechnology’ including enabling technologies for point-of-care devices such as, for example, microfluidics.</td>
<td>Pilot action for new and innovative multi-band photonic and spectroscopic imaging devices together with KET ‘Nanotechnology’.</td>
<td>Outreach to Health insurance providers and medical device manufacturers (KET ‘Nanotechnology’) as well as physicians and clinicians for the deployment of Biophotonic technologies in health. This includes actions for classification of products and standardisation. Pilot action for low-cost and fast analytical methods for process analytical technology (PAT) initiative together with KET ‘Biotechnology’.</td>
<td>Pilot action for low-cost and fast methods to control water and food safety/quality which are close to commercialisation together with KET ‘Biotechnology’.</td>
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2.4 Emerging Lighting, Electronics & Displays

Main socio-economic challenges addressed

This topic deals with a broad palette of inter-related photonics technologies, each showing different times to market, notably, LED (Light Emitting Diodes), OLED (Organic Light Emitting Diodes), OPV (Organic Photovoltaic), Flexible Electronics based on OLE (Organic Large Area Electronics) and Display technology.

Each of these technologies offers substantial contributions towards solving the grand societal challenges defined by the European Commission:

- Displays for medical diagnostics, SSL (Solid State Lighting) offering the optimum lighting conditions for lack of daylight, and Flexible Electronics unlocking personalised diagnostics and treatment, will impact Health, demographic change and well-being.
- SSL reducing lighting energy consumption by a factor of three, and OPV generating clean energy locally, will substantially contribute to Secure, clean and efficient energy and indirectly to Climate action, resource efficiency and raw materials.
- OPV integrated into cars and SSL road lighting as part of traffic management systems will play a role in the realisation of Smart, green and integrated transport.
- Innovative Human Machine Interface using Flexible Electronics, and Display technology for rich visual information everywhere and at any time, will be highly instrumental in the realisation of Inclusive, innovative and secure societies. It is indisputable that ubiquitous connectivity will be a prerequisite for making this happen.

Major photonics needs

The market share of LED technology is rapidly increasing, and it is projected to become the dominant lighting technology before the end of the decade. This change in technology will allow the business to transition from light sources to intelligent lighting solutions. While the present added value of intelligent lighting clearly rests with its energy saving and the consequent reduced carbon footprint, most people are still reluctant to commit themselves to this technology because of the lack of a convincing proof of its economic viability. Furthermore, the benefits of lighting on health and well-being are anticipated to generate even more added value, and so justify further investigation.

The sustained research efforts over recent years have resulted in a steady increase in performance of both OLED and OPV technologies. For these now to become competitive with LED technology and Si-PV (silicon based photovoltaic) technology respectively, a clear breakthrough in cost perfor-
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Performance ratio will be needed, requiring, amongst other things, a massive investment in production equipment.

The development of Flexible Electronics is now offering a variety of new functionalities, having the potential to open up a completely new branch of industry. This European industry will be built around a large number of SMEs, each of them targeting specific application domains with their customised devices, complemented by existing large companies. Flexible Electronics will also unlock innovation in traditional industry segments, such as printing, plastic moulding, paper, and even textiles. In order to respond quickly to the demands of the market, all these companies will need access to flexible production facilities. Considering the current limited availability of financial resources, such capital investments will present a clear challenge.

Despite the display market being dominated (in terms of production volume) by players from Asia Pacific, Europe has maintained its position of strength in material supply, production equipment and visualisation systems. The display industry is currently shifting its focus from LCD (Liquid Crystal Display) towards OLED technology for direct-view displays, from lamps towards LEDs for micro-displays, and towards high brightness LEDs or solid-state lasers for projection displays. 3D displays that do not require special viewing glasses will be the next step in televiusal experience, ultimately enabling remote collaboration. This will require the development of display systems showing a resolution exceeding that of current HDTVs by at least a factor of 100. The ubiquitous presence of displays will continue to create profitable niches, answering different needs throughout the European market.

Involvement of Value Chain Partners

With respect to energy efficiency and carbon footprint reductions, the involvement of public authorities will be critical for pinpointing the added value offered by SSL technology (encompassing LEDs and OLEDs). Indeed, public authorities own a substantial part of the existing infrastructure for both indoor and outdoor lighting, so, by acting as a launching customer for SSL, public authorities will be able to benefit directly from the savings offered by this technology. Additionally, guided by the early feedback from the initial launching customers, the SSL industry will be able to achieve a much faster rollout of this technology.

Fragmented information on the effect of incumbent lighting technology on people’s health and well-being is already available. However, with the advent of SSL technology the spectral, spatial and temporal distribution of lighting can be readily adjusted, offering as yet unexplored new opportunities. To investigate and better understand how tailored lighting conditions could impact the health and well-being of people, the direct involvement of end-users and experts will be required, the latter drawn from the fields of medical science, gerontology, psychology and sociology. In addition to its impact on humans, tailored lighting conditions could also affect animals and plants. Therefore, close collaboration with experts from the biological and agricultural domain will be essential, allowing the potential impact of tailored lighting on the reliability and efficiency of global food supply to be assessed.

The building of a manufacturing infrastructure for OLED, OPV and Flexible Electronics will require close collaboration with both production equipment...
industry and material suppliers, so as to ensure that the essential requirements for speed, cost and flexibility can be met.

OPV offers significant advantages over Si-PV for the direct integration of energy generation into building components, and it is expected to play a major role in facilitating the creation of urban systems around solar energy. Close collaboration with the building industry must be established to maximise the exploitation of this market opportunity.

Breakthrough innovations in Flexible Electronics will result from close collaboration with system integrators and product designers. The development of 3D display systems will be closely dependent on the rollout of ubiquitous high-bandwidth access infrastructure. As a result of its proximity to world leading companies in relevant application fields, such as automotive, avionics, space technology and medical science, the European display industry will be able to make the transition from components towards supplying full visualisation systems. The massive market uptake of intelligent display systems will also depend strongly on the industry’s ability to interact with the user.

**Major Photonics Research and Innovation Challenges**

**LEDs**

As indicated above, the lighting industry will go through a transformation from a supplier of replacement lamps to the provider of intelligent lighting systems, putting the user at the centre of the solution. This also implies that lighting will no longer be seen as a commodity, but instead as a customised solution, adding value to people’s lives.

Many challenges still need to be addressed across the full value chain, from materials right through to lighting systems. With the advent of a new lighting technology, ideal conditions will exist for embedding C2C (cradle to cradle) concepts fully within the lighting domain, driving design for recyclability. At the LED level, research efforts dealing with cost, light quality and efficacy must be continued. Cost and performance in the short term are also major issues at the lamp and engine level, while the continuing standardisation efforts will contribute significantly to the adoption of LED technology by the predominantly SME luminaire manufacturers. Standardisation will also be needed in the field of two-way communication between the various system components, the use of indoor DC grids, the integration of lighting systems into the built environment, and its interaction with the smart grid. Interoperability of the various system components will be critical for market uptake of digital lighting. Specific architectures, tailored to the needs of different market segments, must be developed to allow for the seamless integration of different components within the lighting system, and for the integration of lighting with other functions in smart buildings and communities.

The future of the lighting industry largely depends on its ability to make the transition to new intelligent lighting enabled by Solid State Lighting.
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(OLEDs). This requires close collaboration with the micro-electronics industry to develop new system architectures, including hardware and software architectures and interfaces suited for lighting systems, and in close relation with their (new) applications. Most of the existing ICT architectures are built around the exchange of massive data streams between a ‘limited’ number of nodes (typically, one per office desk, one to two per home). For lighting management, the number of nodes will be much higher (30 light points per home, 100,000 light points for an average community, with each light points consisting of 50–1000 LEDs which may be driven in even smaller subsets), while the data rates needed per node are much lower. Lighting management based on the existing architectures will consequently come at a high cost, severely hampering the market uptake of this technology and applications. The markets served by lighting are of a different nature, requiring different trade-offs between performance, functionality and cost. Moreover, these architectures are likely to vary for the different application domains: outdoor, office, retail and residential homes.

It is clear that the opportunities for new, value added lighting applications are massive, offering energy savings, superior lighting control for context-dependent lighting, improved quality of light, and increased functionalities such as adaptive lighting. In particular, the effect of lighting on people’s health and well-being also needs to be explored, a dimension of lighting seen by industry to offer added value far beyond its immediate energy saving potential. Additionally, SSL could offer exciting new opportunities in crop growth (green houses and city farms), cattle breeding, and fish farming.

The major challenge in the LED domain however is expediting the anticipated massive uptake of intelligent lighting by the market. Whilst other regions have placed their primary emphasis on replacing existing light sources by LED retrofits, the European lighting industry is convinced that intelligent lighting offers greater commercial and ecological benefits. Far greater energy savings can be achieved by combining LED technology with advanced controls, and can also generate significant added value beyond energy saving alone. To speed up its uptake, market demonstration and validation will be essential, and at a level beyond that of existing demonstration projects, which to date have only covered a relatively limited number of light points. The full refurbishment of a medium sized European city would bring compelling evidence of what LED technology can bring to society, and would also showcase the commitment of public authorities to energy efficiency. The vast amount of information that could be gathered from such an action would also act as a springboard for driving the development of building- and district-level energy regulations. Additionally, these large scale demonstration actions also provide a research opportunity, allowing issues related to scalability, system latency, system security, and utilisation due to user behaviour change to be addressed under real life conditions.

The major hurdle facing public authorities considering SSL deployment is the risk that their investments will not yield the anticipated savings. The intervention of the Structural and Cohesion Funds would mitigate those risks for the early adopters, and would be highly instrumental in overcoming
this hurdle. In order to implement quickly the results of the Photonics PPP, the EU Commission should consider establishing a revolving fund with the participation of the European Investment Bank, targeting the fast followers.

The recommendations of the task force on SSL for Cities, established by the EU Commission within the framework of the SSL Green Paper „Lighting the Future”, will be highly instrumental in speeding up the uptake of intelligent LED based lighting in the public domain.

OLEDs (for lighting)

In terms of technological maturity, OLEDs lag behind LED technology, and consequently OLEDs are faced with an LED-dominated market. The penetration of such a market will strongly depend on the OLED’s ability to outperform LEDs in two areas; cost performance and the new market opportunities offered by large area and flexible light sources. Material suppliers will be highly instrumental in achieving the required cost performance breakthroughs, as well as for developing efficient blue light emitters and more efficient OPV layers.

These cost performance issues can only be addressed effectively by making the transition from ‘lab to fab’. Only when pilot lines are deployed, will it be possible to assess the full potential offered by this technology. The highest throughput and lowest costs come through the use of sheet to sheet (S2S), roll to sheet (R2S), or roll to roll (R2R) processes, together with photolithography or laser ablation. Materials represent a major contribution to the cost of OLED products, and this dictates that effort be focused on production processes with low levels of material utilisation.

In laboratory conditions, limited size flexible OLEDs have been realised on metal and plastic substrates. Now it is necessary to scale up fabrication to the pilot line level, allowing a realistic assessment of their market potential to be made.
As with LED technology, system integration for creating user-centric solutions will require the development of hardware and software architectures, enabling the interoperability of light sources, actuators and sensors from different suppliers.

**OPV**

Initially OPV is expected to penetrate dedicated niche markets, subsequently leading to serving new volume markets. A notable example of this would be providing energy to the 1–2 billion people in the world, who will never have direct access to an electricity grid. This could be the perfect stepping-stone for this technology, exploiting the exceptional robustness offered by OPV in comparison to conventional photovoltaic technology. Future mass markets are anticipated to lie with e-mobility and with building-integrated photovoltaics, which are both application fields that will profit significantly from conformable, flexible and transparent solar cells. The European Photovoltaic Industry Association (EPIA) predicts that this massive market uptake of OPV will occur around 2020, allowing sufficient time for OPV technology to improve and outperform conventional Si-PV technology.

The innovation challenges facing OPV are very similar to those facing OLED lighting technology. Major improvements in the cost performance ratio will be required to become competitive with the established Si-PV technology. To achieve this, a doubling of the present efficiency will be needed, as well as a substantial increase in lifetime, and these targets must be high on the research agenda. New materials will play a major role in achieving these improvements. In parallel with this, scaling up fabrication from cells to modules, and the transition from ‘lab to fab’ to manage the complexity of the processes, will both make a major contribution to cost reduction. However, this goal can only be reached through a substantial increase in investment in pilot production facilities. There are clear opportunities for cross-fertilisation between the technologies developed for the OLED lighting and
the OPV industries. For example, whilst OPV will evidently benefit from mass-production methods developed in the OLED industry, the roll-to-roll processes developed for OPV could also benefit the OLED industry.

Flexible Electronics based on OLAE devices

Cheap, mass-produced smart systems built around organic, flexible and large-area electronics will create many new business opportunities. These will make use of what is termed ‘human size electronics’, as well as advanced man-machine interfacing. Examples include electronic labels for logistics, smart packaging, personalised health diagnostics, and medical therapy. To date, most attention has been given to the realisation of generic OLAE devices, but the heterogeneous integration of proven functionalities into systems will pave the way towards industrialisation. Initially these devices will integrate simple functionalities using the existing infrastructure with proven integration technologies. In a subsequent phase, multiple functionalities will be integrated in conformable and flexible systems, requiring new processes and more advanced heterogeneous integration approaches. Most of these innovative devices will include large area photonics devices, such as displays, lighting elements, OPV and photonics sensors.

The first steps for creating open prototyping and small series production facilities have already been made. The recommendations of the COLAE (Commercialisation clusters of Organic and Large Area Electronics) co-ordination and support action will be instrumental in rationalising the existing European production infrastructure. This rationalisation effort should be strengthened to offer start-up companies, existing SMEs and fabless design houses, the opportunity of exploring the full market potential of their product ideas. Although modelling and simulation tools are readily available for silicon-based devices, these are not suitable for complex heterogeneous Flexible Electronics devices. The development of such tools will be essential for achieving a short time to market for new Flexible Electronics devices.

Displays

Displays are one of the most visible expressions of photonics as a key enabling technology. High-fidelity visual communication will increase efficiency and competitiveness, in particular for high added-value applications for remote collaboration between professionals, for example, engineers, business executives, medical doctors, etc. The display demands are very heterogeneous and the preferred display technology will depend largely on the specific end-application, for example, direct-view AMOLED (active matrix OLED), e-paper, projection displays, and near-to-eye displays.

A high priority has been assigned to the development of technology for AMOLED displays because, when compared to conventional liquid crystal displays, this technology is potentially superior in overall image quality, thickness, power efficiency and weight, and all achieved at lower manufacturing cost. Research topics are focusing on improvement of the metal oxide TFTs and organic TFTs, new OLED and film materials for longer lifetime, increases in wall plug efficiency, and the development of curved, flexible and rollable displays.

Specifically for near-to-eye micro-displays, the main challenges include achieving high luminance at reduced pixel size, as well as power reduction. Research topics should therefore focus on new lighting structures and materials, on the optimisation of colour generation, and on new packaging technologies, including improved thin film encapsulation.

The glasses-free 3D display system with >100 views, needed for a truly immersive experience, will require large bandwidth access at the network endpoints. A rich immersive visual experience requires life-size displays with a resolution corresponding to nominal visual acuity. There is a
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steady move towards these targets with increases in the number of views and improved resolution for the displays, and constantly improving network bandwidth and latency on the systems side. Product development and manufacturing need to focus on the integration of sensors. Glasses-free 3D displays will also require the development of a specific production infrastructure for the alignment of different views and testing of the overall experience. In addition to 3D displays themselves, immersive experiences require the integration of visual and auditory capture, haptic feedback, control software, and processing components. The building of a first-of-a-kind true 3D demonstrator will contribute greatly to the development of such a production infrastructure.

Synergy with other Key Enabling Technologies

For all above-mentioned applications, it is essential that the development of photonics technologies be closely aligned with the latest developments in microelectronics technologies. This will allow the adoption of optimum approaches for driving SSL efficiently, managing and monitoring energy usage of lighting systems, driving the display content, and integrating the photonic and flexible electronic devices into larger ICT (Information and Communication Technologies) systems.

Furthermore, new advanced materials and nanomaterials will contribute greatly to the improvement of all the photonics devices discussed. This is particularly the case for OPV, OLED and Flexile Electronics devices.

In addition to this synergy with other key enabling technologies, it would be beneficial if, within the photonics KET, a closer collaboration between the SSL industry and the optical sensor industry were established to speed up the introduction of intelligent lighting systems. Further, by teaming up with life science and health sector, innovation in the domain of flexible electronics for personalised diagnostics and treatment would be greatly accelerated.

The following table shows the major innovations actions identified for this technology sector. They are the logical consequences of actions already commenced in the FP7 framework programme. The timing of each of these actions is chosen so
## Roadmap for 2014–2020

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<tr>
<td><strong>LED</strong></td>
<td><strong>R</strong> Smart lamps &amp; modules</td>
<td><strong>LSD</strong> Intelligent lighting for cities</td>
<td><strong>R</strong> Biological efficiency</td>
<td><strong>R</strong> Biological efficiency</td>
<td><strong>S&amp;R</strong> Building code</td>
</tr>
<tr>
<td></td>
<td><strong>CSA</strong> Biological efficiency</td>
<td></td>
<td></td>
<td></td>
<td><strong>R</strong> Open system architecture</td>
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<td><strong>OLED</strong></td>
<td><strong>R</strong> Cost-performance breakthrough</td>
<td><strong>P&amp;MS</strong> High-speed production facility for flexible OLEDs</td>
<td><strong>R</strong> Materials for cost performance</td>
<td><strong>R</strong> Integration into building components</td>
<td><strong>R</strong> Open system architecture</td>
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<td><strong>OPV</strong></td>
<td><strong>R</strong> Cost-performance breakthrough</td>
<td><strong>R</strong> Off-grid solutions</td>
<td></td>
<td><strong>P&amp;MS</strong> Adaptable low-cost high-speed production facility</td>
<td><strong>R</strong> Integration into building components</td>
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<tr>
<td><strong>Flexible Electronics</strong></td>
<td><strong>R</strong> Heterogeneous system on foil</td>
<td><strong>CSA</strong> COLAE</td>
<td></td>
<td><strong>R</strong> Modelling &amp; simulation tools</td>
<td><strong>P&amp;MS</strong> Adaptable open-access production facility</td>
</tr>
<tr>
<td><strong>Displays</strong></td>
<td><strong>R</strong> systems for ultra-high performance and viewing experience</td>
<td></td>
<td><strong>P&amp;MS</strong> Upscaling of performance materials and processes</td>
<td><strong>FoKD</strong> 3D glasses-free multi-view (&gt; 100 views)</td>
<td><strong>P&amp;MS</strong> 3D glasses-free multi-view and near-to-eye displays</td>
</tr>
<tr>
<td><strong>Key:</strong></td>
<td><strong>CSA</strong> Co-ordination &amp; support action</td>
<td><strong>LSD</strong> Large-scale demonstration &amp; market validation action</td>
<td><strong>FoKD</strong> First-of-a-kind demonstration action</td>
<td><strong>S&amp;R</strong> Standardisation &amp; regulation action</td>
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as to build on the results of these previous actions, and on the synergies existing between the different technologies.

Market validation should be an integral part of innovation projects, irrespective of whether their focus is on applied research or on piloting. In some cases, the cost of demonstration and validation will be too high to be integrated in such actions. Therefore two new types of instruments are proposed, First of a Kind Demonstrations, targeting complex systems, and Large-scale Demonstration & Market Validation Actions, complementing the existing demonstrations within the CIP programme.

**Expected impact for Europe**

In the near future, solid-state light sources (LEDs and OLEDs) will outperform all other light sources in terms of efficiency, and will achieve potential energy savings up to 30–50%. A further 20–50% could be saved if SSL technology is combined with intelligent light management systems that regulate light output according to ambient lighting conditions or people’s presence and activities. Overall therefore, advanced SSL could cut present-day electricity consumption for lighting by about 70%.

The realisation of such digital lighting solutions would result in huge benefits:

- more than €300 billion saved annually on the global energy bill
- global reduced emission by more than 1000 million tonnes of carbon dioxide per year
- the economy boosted by strengthening Europe’s industrial position in lamps, luminaires and driver electronics, which together already employ over 150 000 people
- society at large benefiting from the greater visual comfort of superior lighting solutions, and reduced light pollution through more closely focused lighting

Recent projections by the European Lighting Industry (ELC-CELMA) indicate that by 2020 more than 95% of lighting turnover will be based on SSL technology, equating globally to €52 billion for luminaires and €12 billion for lamps and lighting engines. These figures indicate a ten-fold increase in LED luminaire sales and a four-fold increase in LED lamp sales compared to present levels. Comparable figures for the EU27 show similar growth rates at €18 billion and €4 billion respectively.

The OPV market is predicted to grow to €630 million by 2022, though still representing less than 1.5% of the predicted total PV market. However, around that time OPV is expected to have reached sufficient maturity to allow for direct integration into building materials, thereby opening up a huge mass market. By 2016 the world market for rooftop building integrated photovoltaics (BIPV) is predicted to reach €2 billion, and the market for wall integrated PV to reach €1 billion. The latter market will profit greatly from the advent of OPV, and is expected to exceed the existing Si-PV market by a factor of at least 10.

The present Si-PV off-grid market is approximately €2.4 billion with an estimated CAGR of 9–15%. Conservative estimates indicate that the off-grid OPV market could easily match this value.

Flexible Electronics based on OLAE devices are expected to enable completely new markets, offering large business opportunities to specialised start-up companies, as well as to existing large electronics companies. Additionally, Flexible Electronics will also drive innovation in the more traditional paper and plastic industries. As with all emerging technologies though, the prediction of reliable market forecasts is difficult, particularly because Flexible Electronics could impact so many market segments, including consumer goods, building components,
transport, healthcare, gaming, packaging & logistics, food, and pharmaceutics. Specific information on the consequent economic impact in terms of either turnover or job creation is therefore not currently available. However, the overall OLAE market, including Flexible Electronics devices, OLED lighting and displays, and OPV, is expected to grow from its present value of €1 billion to between €100–200 billion, depending on the source consulted.

Display-enabled rich visual communication will trigger the next communication revolution for professional users, offering attractive alternatives to the less effective collaboration tools of today, thereby avoiding the need for many travel-intensive, face-to-face meetings. In Europe alone, this is expected to result in a 20% reduction in business trips, saving 22 million tonnes of CO₂ emissions per year. At the same time, the deployment of such systems will contribute directly to increased productivity in several other markets, especially in the service sector. This sector alone generates 75% of the EU GDP, and increased productivity accounts for 50% of its annual growth. Europe is ideally placed to establish a leadership position in this sector, being home to many of the largest system integrators and having unique strengths in end-user centric and application-driven design.

As well as the advanced 3D displays themselves, additional components will be required to create a rich visual experience for the user. The business multiplication effect thus generated is estimated to be a factor of 3 for the low-end segment, rising to a factor of 10 for the high-end segment. It is estimated that global sales of advanced 3D displays will reach €10 billion by 2021, with a 35% share for European companies, and a show CAGR of 15% over the period 2021–2025. This will increase the overall annual turnover to some €36 billion by 2025. The realisation of this ambition will require the development of a European eco-system. The development of such systems will require high-quality advanced engineering as well as the involvement of experts in the fields of psychology, sociology and user experience. This is expected to generate approximately 5000 highly qualified new jobs in science and engineering. Also, the job creation in production is predicted to reach 14 000, along with an additional 28 000 jobs in sales and services.

In the short term, the Photonics PPP will contribute greatly to the consolidation of the European lighting industry’s current number one position, and further offers the opportunity to outpace the competition from other regions through focussing on the added-value lighting, rather than cost alone. In the longer term Organic Large Area Electronics has a huge potential to build new businesses and new jobs for Europe.
2.5 Security, Metrology & Sensors

Main socio-economic challenges addressed

Today, over 70 million organic and inorganic substances are on record\(^9\), and for most of these, little is known about their potential danger to humans. Although only a small fraction of this plethora of molecules are marketed and released into the environment, our society is confronted daily with a growing number of potentially hazardous chemicals.

Well-known examples of the reality of this threat include the contamination of milk with melamine, of drinking water with herbicides and fungicides, of wine with glycol, and of plastic food containers with hormone-like components (endocrine disruptive compounds). As a result, increasingly and often justifiably, our citizens feel threatened by potential hazards contained in the foodstuffs they eat and drink, and in the air they breathe.

Much worse, naturally occurring molecules, produced by microorganisms within our food, represent an even larger threat to our society’s health. The WHO estimates that more than two billion illnesses are caused by unsafe food every year, and in the developing world alone, two million children die annually from contaminated food and water\(^10\). In Western countries, 5–10 people per million inhabitants die every year from food borne diseases\(^11\). In the USA alone, this claims an annual death toll of more than 3000 people, costing up to $35 billion in medical costs and lost productivity\(^12\).

Already today, we possess the biochemical and technical means to identify small numbers of molecules or microbes in a sample. However, all these methods are expensive and time-consuming. Optical methods may provide breakthrough solutions to this highly relevant problem, overcoming the traditional, tedious chemical lab analysis. For example, it is known that measurement techniques in the mid-infrared (MIR) spectral range, known also as the fingerprinting/diagnostic region, are highly specific to individual molecules, even able to distinguish between isotopes in their atomic constituents. Optical methods can also be extremely sensitive, exploiting the existence of photonic sensors capable of detecting the arrival of single photons with sub-nanosecond timing precision. Additionally, very sensitive and highly specific novel diagnostic techniques are emerging, such as Raman and LIBS spectroscopy, whose performance would be much improved if operation could be extended into the infrared spectral range. However, the major problem with the current photonic devices and detection systems capable of achieving the required specifications is that they are much too expensive for the realisation of affordable, practical sensing systems! Consequently, if the challenges described above for food/air/water/environmental safety and security, are to be solved, it is essential that multi-band photonic sensing is developed, leading to a safer and more secure society. Once available, these photonic innovations will lead to numerous additional applications, further improving many aspects of our daily lives.

Major Photonics needs

The near infrared (NIR) spectral range (0.8–2.5 µm) is already employed for many tasks in food inspection (moisture sensing, content of protein/

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9 On-line Registry of the Chemical Abstracts Service (CAS) of the American Chemical Society: http://www.cas.org


12 Wikipedia article on Foodborne Diseases: http://en.wikipedia.org/wiki/Foodborne_illness
2. Photonics Research and Innovation Challenges

Photonics technologies can help retailers and customers to judge the ripeness of fruit and vegetables, and so reduce the percentage of discarded food. © Fotolia

Photon measurements are used for the screening of water for contamination. © Fotolia

Oil/fat/starch/sucrose/fibres, detection of foreign particles and nut/fruit-stone inclusions, quality and ripeness of fruit and vegetables, etc.), as well as in recycling and waste treatment (sorting of wastepaper, cardboard, plastics/polymers, fuels, industrial waste). The diagnostic mid-infrared (MIR) region (2.5–7 µm) yields information about the presence of functional groups in samples, enabling, for example, the identification of numerous volatile organic compounds (VOCs) in gases. The fingerprint MIR region (7–11 µm) allows the different compounds in a sample to be distinguished, due to the specific spectral ‘fingerprint’ of each molecule in this spectral domain, utilising the large existing collections of reference spectra in vapour and condensed phases. Finally, the far infrared and THz region (up to 1000 µm) offers complementary fingerprinting capabilities using specific spectral signatures, with the additional benefit of deep penetration in standard packaging materials such as paper, plastics or textiles.

Some of these critical measurements in the extended infrared (EIR) spectral domain (1–1000 µm) can be performed today, albeit with very expensive active and passive photonic components. For example, a moderate-power MIR laser costs €10,000, an uncooled FIR bolometer camera costs at least €50,000, a 128x128 NIR image sensor (InGaAs) costs €4000, a single photodiode (InAsSb) for the 1–5 µm band costs €1000, and even a single silicon microlens (for wavelengths above 1.1 µm) costs €50. Clearly it is not currently possible to realise cost-effective EIR sensor devices and make them affordable for general use, despite the abundance of highly relevant practical applications operating in the infrared spectral domain. While the important ultraviolet and visible (UV/VIS) spectral domain is accessible using the ubiquitous silicon photodetectors, we have to progress beyond silicon in order to meet the challenges of the EIR domain.

The challenge is therefore clear – we need to develop new high-performance yet affordable photonic devices. Specifically:

- quantum-noise-limited active optoelectronic devices (coherent and incoherent sources, detectors) based on inorganic/organic semiconductor materials, offering the appropriate EIR properties.
- CMOS-based charge detector platforms with low-noise/low-power/high-speed-readout performance that can be combined with many classes of semiconductor materials.
- novel measurement techniques to exploit the beneficial properties of such newly developed EIR detectors for industrial applications.
- affordable non-toxic cooling solutions (in particular thermo-electric coolers) for EIR photosensing and light emission platforms
- a wide range of low-cost passive optical components, to enable the integration of complete EIR systems.

The overall goal is to conquer the EIR spectral range with a complete toolbox of low-cost active and
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Photonics is essentially a three-dimensional challenge, and current microelectronic planar fabrication methods have only limited capability to be extended into the third dimension. Precise, low-cost photonic microsystems require novel, cost-effective, 3D fabrication methods. These combine a very high degree of integration with a minimum number of assembly steps, inherently providing the micron/sub-micron resolution necessary for photonic microsystems. Therefore, close collaboration with the KET Advanced Manufacturing will be essential.

Finally, a key element for any successful innovation process is the early involvement of potential application partners, so as to ensure that the designed systems really meet the specifications and expectations of the end users. A vast range of application domains is anticipated for the envisaged multiband sensor technologies, so early contact with several of Europe’s Technology Platforms (ETPs) will be necessary to ensure systematic and coordinated goal setting, R&D activities, and practical verification. These include specifically, the ETPs for Nanomedicine, Food, WSSTP (Water Supply and Sanitation Technology), GAH (Global Animal Health), SMR (Sustainable Mineral Resources), EuMaT (Advanced Engineering Materials and Technologies), EPoSS (Smart Systems Integration) and Industrial Safety.

Major photonic research & innovation challenges
The guiding principle for all the envisaged R&D efforts is to achieve affordable effectivity for the measurement task. For example, it is pointless to develop an EIR laser source with record quantum efficiency at a wavelength, for which no high-sensitivity photodetectors are available. For all components of a complete photonic measurement system, a sensible cost-performance balance must be identified, so that the resulting system solves the given measurement task in a reliable and affordable manner.

Involvement of value chain partners
The challenge of providing such multi-band photonic sensing for a safer and more secure society is enormously ambitious, because true innovation in this highly interdisciplinary domain requires exceptional science and engineering capabilities combined with advanced production skills.

The materials challenges are significant, and a close collaboration with the KET Advanced Materials will be essential for solving them. In particular, the necessary inorganic/organic optoelectronic materials are not very common, the demands on inorganic crystalline purity are very high, and only a few organic semiconductors are known possessing a cut-off wavelength above 1 µm. Additionally, efficient thermoelectric cooling requires new novel material systems that will be affordable and non-toxic, yet very few alternatives to today’s bismuth tellurides have been commercialised to date.

Certain materials required for NIR/MIR active optoelectronic devices must be formed as nanoparticles to be effective. Also, an important class of MIR lasers and detectors employs the quantum cascade mechanism, requiring precise design and fabrication of hundreds of nanometer-thin layer structures. To solve these nano-engineering challenges, collaboration with the KET Nanotechnology will be critical.

Usually the production cost of optoelectronic devices is dominated by the packaging process, and not by the employed materials themselves. To minimise such costs, the techniques and fabrication facilities developed for microelectronics have and will be used wherever possible for photonic device fabrication. Consequently, this has resulted in very close ties with the KET Micro- and Nanoelectronics.

The development of multi-band photonic sensing will make a huge contribution towards a safer and more secure society.
EIR sources
As a consequence of the low concentration of many critical analytes, there is a huge need of cost-effective, narrow-band, medium-power (1–100 mW) light sources, allowing the measurement process to be done quickly and with the required resolution. Of particular interest are solid-state lasers, such as QCLs (Quantum Cascade Lasers), VECSELs (Vertical External Cavity Surface Emitting Lasers), VCSELs (Vertical Cavity Surface Emitting Lasers), and fibre lasers. Since many technologies utilise electronic lock-in methods, it must be possible to modulate the lasers electrically. For stable, efficient operation in the MIR/FIR, the lasers must be cooled and temperature-controlled, and care must be taken that these cooling requirements do not dominate the production cost of the complete laser sub-system. For low-cost laser systems, electrical emission wavelength tuning capability is desirable, with tuning ranges of several 10 nm or up to a few 100 nm.

A specific goal is the development of a family of tunable EIR light emitters. Complete laser system costs, including cooling, modulation control, and electrical power supply, should reduce to a few €100.

Additionally, NIR/MIR light-emitting diodes (LEDs) may be of interest as an alternative source in sensing systems that do not require narrow-band illumination. New and more powerful sources for wide-band IR spectroscopy are also needed, such as those based on fibre supercontinuum effects, offering convenient coupling to optical fibres. Here the goal is the development of NIR/MIR broadband light sources offering emission powers ≥1 mW, with ≤ €1 cost in large volumes.

EIR photodetectors (0D, 1D, 2D)
A large number of materials and detector types are currently employed for point, linear and image sensor devices for the NIR/MIR spectral range, including pyroelectric detectors, thermopiles, microbolometers, narrow-bandgap photovoltaic detectors, Schottky barrier detectors, extrinsic photoconductors, multi-quantum-well semiconductor heterostructures for QCDs and homo/heterojunction internal photoemitters (HIP). The challenge is to detect as many incoming photons as possible, while reducing the effects of dark current. This corresponds to the primary task of maximising the sensor’s detectivity, which is equivalent to minimising its noise equivalent power. At the same time, material and packaging costs must be reduced to increasingly lower values, and cooling requirements kept to a minimum.

The primary goal is to develop novel types of highly cost-effective solid-state NIR/MIR sensors, based on new or optimised material systems, and ideally produced using well-established microelectronic fabrication techniques. It must be straightforward to produce these sensors as point detectors, line sensors or image sensors, and they must have a performance close to the ideal detector limit. Point detectors should cost no more than €10, whilst line or image sensors should cost less than €100, including the cooling devices.

CMOS-based single-photon NIR image sensing
It has been demonstrated recently that novel types of CMOS-based image sensors are capable of detecting individual incident photons at room temperature. Accepting the need for cooling, it should also be physically possible to extend the cut-off wavelength from silicon’s 1.1 µm to higher values in the NIR, while still being sensitive to each incident photon. This requires scientific progress in two domains. Firstly, novel CMOS-based charge detection circuits with sub-electron readout noise performance are needed. Secondly, it will be necessary to combine these charge detector circuits with semiconducting materials exhibiting a cut-off wavelength above silicon’s 1.1 µm. Promising candidates include nanostructured (black) silicon, inorganic narrow-bandgap crystalline semiconductors (such as InGaAs), or novel types of organic semiconductors sensitive in the NIR spectral domain.
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The primary goal is to employ CMOS technology for the integration of 2D arrays of charge detectors offering sub-electron readout noise, with suitable inorganic/organic material systems, and resulting in affordable single-photon resolution image sensors covering a large part of the NIR spectral range. Such CMOS-based single-photon NIR image sensors with one Megapixel should cost less than €100.

Low-cost, high-performance micro-coolers
A miniature refrigeration device is an indispensible element for any stable EIR light source and low-noise detector. Many physical methods are known for transporting heat, involving mechanical, magnetic, electrical, acoustic, incoherent/coherent radiation or thermal energy. In photonics, the predominant refrigeration device is the thermo-electric cooler (TEC), based almost exclusively on bismuth-telluride. Today's TECs are highly inefficient, typically exhibiting only 5–8% of the Carnot efficiency, compared to the 40–50% of a vapour-compressor. Novel solid-state concepts, such as the thermionic converter, can potentially go beyond 50% efficiency, and they can be manufactured with well-established microelectronics fabrication technology, their production can be very cost-effective and high levels of integration with other photonic elements can be achieved.

Passive optical devices
Development of optical instruments in the UV/VIS/NIR spectral domain is aided significantly by the availability of many passive optical elements such as lenses, mirrors, beam-splitters and gratings. For large volumes, manufacturers in Asia provide such elements with unit prices well below €1. The materials and technologies used for correspond-
This is an indispensable step for bringing inexpensive, multi-spectral/hyper-spectral measurement systems into production lines. To this end, account must be taken of the specific spectral and sensing properties of the new sources, sensors and other optical components in the EIR. While most of today’s measurement techniques rely on visible light and silicon sensors, the great challenge is to develop a new generation of measurement systems fully exploiting the combination of spatial information with multi-spectral data.

Complete integrated photonic microsystems
Photonics has profited enormously from the adoption of planar fabrication and integration techniques developed for micro- and nanotechnology. Precise concurrent production of a number of photonic components in one fabrication step (for example using injection moulding or other low-cost replication techniques) results in products that do not require costly post-production alignment procedures, and thus achieves much lower fabrication costs. However, optical instruments working in the MIR spectral domain are still so expensive that it is not yet necessary to adopt the established integration techniques known from the visible spectral range. Since the mechanical tolerances are more relaxed in the MIR spectral range than in the visible, advanced low-cost additive manufacturing techniques might be employed, offering novel opportunities for the European manufacturers of integrated photonic microsystems.

The goal is to develop precise yet low-cost fabrication methods for the production of small and large quantities of complete, readily aligned photonic microsystems operating in the EIR spectral range.

Comprehensive photonic solutions for high-impact applications
The ultimate goal of any research action within the framework of Horizon 2020 must be an innovative response to highly relevant socio-economic challenges. For the present case, this implies that complete multi-band photonic sensing solutions must be developed, providing for a safer and more secure society, through full utilisation of the as yet largely unexploited potential of the EIR spectral range. For this reason, there are two important problem domains that must not be neglected:

1. The main applications addressed are in the area of food/air/water/environmental safety and security, requiring affordable, simple yet reliable examination of gaseous, liquid and solid samples. Therefore, sample preparation is an important part in the development of comprehensive photonic solutions. If the concentration of the sought analytes is too low, it must be increased, for example through chromatographic methods, so that the optical measurement process generates sufficient signal. Hence, the development of accompanying consumables such as microfluidic, gas diffusion, and convection and optofluidic cells must be an integral part of the overall system development.

2. A central part of most EIR fingerprint measurements is the comparison of measured spectral data with the contents of a reference library. Much care and effort must be devoted to ensuring the availability of such a library, either through direct measurements or from compilations of available resources. This can then be used to provide a stable, efficient and dependable algorithms for the reliable determination of the constituents and their concentration in an analysed sample.
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**Expected impact for Europe**

Europe could become the world leader in non-contact fingerprint diagnostics by commercially exploiting the as yet under utilised domain of multi-band UV/VIS/EIR photonic sensing for a safer and more secure society. Many of the scientific and technological capabilities to exploit the EIR spectral domain are already located in Europe. These include novel materials related to microelectronics, active/passive device fabrication, packaging of photonic components, development and production of photonic sub-systems, as well as development and deployment of comprehensive system solutions.

The envisaged EIR measurement techniques are not a replacement for high-sensitivity biochemical assay-based measurement systems, but instead provide a complement, bringing affordable, label-free fingerprint analysis methods from the laboratory into the hands of the consumer. In practice, these techniques will find much wider use than merely in the applications described above:

**Food:** EIR analysis methods will be used for checking raw foodstuff materials, in-line controlling of manufacturing processes, confirming the safe sealing of packaged goods, and for assuring the quality of processed food. The non-contact nature of photonics enables such checks without pre-processing food samples, even without opening the package. EIR analysis methods will also enable retailers and customers to judge the ripeness of fruit and vegetables, and to determine whether food is still safe to eat. This could help to reduce significantly the percentage of discarded food, which, according to a recent UN report, currently amounts to about 30% of all produced food\(^{13}\). The global market for processed food is more than €2.6 trillion, and for food processing machinery and equipment it is approximately €35 billion\(^{14}\).

**Environment:** Contamination of our environment, be it fresh water resources, seawater, soil, or the air we breathe, is an increasing worry for our industrialised society. By allowing the screening of large volumes of air, water and soil probes, EIR analysis methods provide an excellent complement to the more specific and highly sensitive biochemical analysis techniques. An important application is the detection and prevention of oil contamination in seawater, for example, through the routine water inspection in ship ballast tanks. The global market for environmental monitoring is about €10 billion\(^{15}\).

**Water:** Drinking water and treated wastewater alike must fulfill certain purity requirements. EIR measurements will be a valuable complement to existing biochemical analysis techniques in screening large volumes of water for contaminations in moderate concentrations. The global market for water analysis instrumentation is about €1.5 billion\(^{16}\).

**Efficient combustion:** Many of our sources of electricity, heat and light are based on combustion processes. Frequently, the employed fossil or renewable fuel is not of constant quality, and the combustion process has to be adapted for varying fuel quality. It would be of great value to know the composition of the fuel used, be it in domestic heating systems or in public buildings, in moving vehicles or especially in ships. The same is true for the analysis of the exhaust gases. In-line measuring

\(^{13}\) J. Gustavsson et al., *Global Food Losses and Food Waste*, Food and Agriculture Organization (FAO) of the United Nations, Rome, 2011

\(^{14}\) *Food Processing Machinery and Equipment – A Global Strategic Business Report*, Global Industry Analysts Inc., San Jose (USA), May 2012

\(^{15}\) *Environmental Sensing and Monitoring Technologies: Global Markets*, BCC Research, Wellesley (USA), October 2011

\(^{16}\) *Water Analysis Instrumentation: A Global Strategic Business Report*, Global Industry Analysts Inc., San Jose (USA), August 2011
### Roadmap for 2014–2020

#### Critical path from science to market

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<td>1. Demonstration of EIR system concepts with high application potential. 2. Invention of new potent low-cost EIR components.</td>
<td>1. Field tests with demonstrator systems. 2. Realisation of new EIR component prototypes.</td>
<td>1. Design and realisation of low-cost versions of successful systems using new EIR components. 2. Ramp-up of EIR component and sub-system production.</td>
<td>International market penetration with new low-cost EIR systems, components and applications.</td>
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#### Technological challenges

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#### Research actions

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#### Innovation requirements

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<td>Buildup of European network of competence in EIR devices and systems. Involvement of existing producers of photonic materials and components in Europe. Search for secondary applications of EIR spectral range with high value.</td>
<td>Establishment of supply chains for advanced EIR optoelectronic components and metrology systems with emphasis on European suppliers of high-margin production steps. Support of European startups in the EIR domain, created as a result of novel concepts found in the first phase of the program.</td>
<td>Involvement of end users in primary and secondary application fields: Food/air/water/environmental safety and security, medical diagnostics/recycling/combustion &amp; building control/surveillance &amp; public place security/anti-counterfeiting. Demonstration actions for all selected showcase examples.</td>
<td>Joint field tests with end users. Buildup of user communities, producing and exchanging databases and practical experiences. Support of system design and application startups created as a result of the previous demonstration successes.</td>
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#### Cross-cutting Key Enabling Technologies (KET) issues

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<td>Involvement of KETs relevant for material and device fabrication: Advanced materials, micro nano-electronics and advanced manufacturing.</td>
<td>Joint selection of high impact application areas in safety &amp; security of food, air, water &amp; environmental control, in close collaboration with other KETs and ETPs. Elaboration of secondary applications as discussed below (medical, waste treatment, building control, anti-counterfeiting, traffic safety, industrial metrology, etc.).</td>
<td>Buildup of user groups and European competence network in EIR system design and applications. Collaboration with other KETs and ETPs in the elaboration of system specifications and conditions for practical applications of the developed concepts, devices and sub-systems in other domains.</td>
<td>Promotion of the EIR spectral range for applications beyond those demonstrated in the program. Identification of applications with highest socioeconomic values created in Europe.</td>
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of the produced levels of $O_2$, COx and NOx makes it possible to optimise the combustion process, increasing efficiency, whilst producing the minimum volume of harmful gases. In all these applications, it has already been proven that EIR measurements can provide viable solutions, but monitoring system prices must be reduced by 1–2 orders of magnitude before EIR fuel quality checks and exhaust gas analysis can become economically viable.

Building control: Stricter building codes for environmentally friendly houses involve greater insulation of buildings, to such a degree that internal air quality is increasingly becoming an issue. In particular, levels of CO$_2$ and some volatile organic compounds causing unpleasant odors must be controlled to optimise ventilation. The high prices of existing EIR analysis systems imply that such solutions will only be applied to large public buildings. Price reduction would make it possible to provide every low-energy house with this much-needed capability.

Recycling and waste treatment: The sorting of wastepaper, cardboard, plastics/polymers, fuels, industrial waste, etc. for recycling or proper disposal can be done at high speed using NIR/MIR analysis systems. The current high cost means that only larger facilities have such sorting systems. Lower prices of these analysis devices will allow much broader utilisation of automatic sorting systems. Also, networks of local automatic plastics recognition and tracking systems can be realised for plastic waste in rivers, lakes and seas, thus reducing the environmental contamination of plastic trash. The total world waste market (from collection to recycling) is about €300 billion.\(^\text{(17)}\)

Optical metrology: Optical 3D measuring systems are essential components for high-precision fabrication, as safety measures in automatic doors and robotic workstations, in private and public transportation, as well as in novel user interfaces for computers and games. The precision of these metrology systems could be substantially increased and their ubiquitous outdoor use would be made possible if the interference of background radiation (sunlight) were reduced. According to the European eye safety norm EN 60825, the maximum permissible exposure in eye-safe metrology systems may be increased by more than 100,000 times by shifting the wavelength of the active light source to the range of 1.5–1.8 $\mu$m, beyond the reach of silicon.\(^\text{(18)}\) The global optical metrology market is about €20 billion.

Medical diagnostics: Novel approaches to non-invasive medical diagnostics include breath analysis, and it has been conclusively shown that a number of relevant diseases, in particular cancer and diabetes, can be detected by analysing the patient’s breath for the presence of specific combinations of biomarker gases. Such measurements can be done using non-invasive optical techniques alone, operating in the MIR spectral range. Providing that prices of such breath analysers drop substantially,

it is conceivable that each general practitioner practice could be supplied with such an instrument for rapid, low-cost and early screening, as well as monitoring the progress of therapeutic regimens. The global in-vitro diagnostics market is €45 billion.

Secure society: Enhanced protection of travelers at airports and train stations, or visitors in public spaces is a major application area. For example, the detection of explosives through ‘fingerprint’ gas analysis, improved recognition of individuals through EIR signatures (distribution of veins in face and hands), more effective identification of prohibited or dangerous goods through effective large-scale cargo screening, and improved surveillance in public spaces by identification of suspicious persons or luggage items with unusual MIR profiles. The worldwide security equipment market is €76 billion.

Safer traffic: The presence of pedestrians or animals in the road is straightforward to detect through the infrared radiation emitted by warm bodies, so MIR enabled night-vision offers significant safety enhancements for night driving. Optical time-of-flight 3D imaging for reliable daytime use in automotive vehicles requires the use of the higher illumination powers that are possible in the NIR spectral range (as discussed above). Finally, rapid low-cost checks for drivers possibly under the influence of drugs or intoxicating beverages are readily performed in the NIR/MIR spectral range, without the use of any consumables. More than 60 million cars are produced worldwide every year, all of which could benefit from the added safety offered by these IR-enabled sensing devices.

Anti-counterfeiting: Counterfeiting accounts for 5–7% of world trade every year, corresponding to almost €500 billion. When health-related products, such as pharmaceutical drugs, food or beverages are counterfeited, the indirect safety costs of counterfeiting exceed the already enormous economic damage. The NIR/MIR spectral range offers novel approaches and low-cost verification means to label products in all industrial branches, including personal identification items, such as passports or identity cards, as well as banknotes, credit cards, etc..

Non-destructive testing: Safe construction of mechanically challenging structures requires reliable, non-destructive testing (NDT) of the employed materials and components. In particular, the demand for stronger and lighter weight parts leads to a replacement of metallic elements with composite materials, such as carbon fibres, glass fibres and composite honeycombs. As an example, a new Boeing 782 Dreamliner consists of 50% (by weight) of such composite materials. Conventional NDT techniques (e.g. X-ray, ultrasonic, eddy current inspection) need to be complemented with novel inspection techniques tailored for these composite materials. The FIR spectral range offers unique advantages for the detection of surface and subsurface damage, such as delamination, impact micro-fractures, porosity, etc..

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19 Strategic Analysis of the Global In Vitro Diagnostic Market, Frost & Sullivan, San Antonio (USA), July 2010
20 World Security Equipment to 2014 – Demand and Sales Forecasts, Market Share, Market Size, Market Leaders, The Freedonia Group, Cleveland (USA), December 2010
22 ACG Statistics on Counterfeiting and Piracy, The Anti-Counterfeiting Group, High Wycombe (UK), 2010
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2.6 Design and Manufacturing of Optical Components and Systems

Main socio-economic challenges addressed

As a fundamental pillar of modern industry, a Key Enabling Technology, photonics underpins solutions for the widest possible range of socio-economic needs. For example, the Internet of today depends on the ubiquitous application of photonics in telecommunications infrastructure and, as our society become ever more information-intensive, our needs in this respect will continue to grow. Laser-based techniques have revolutionised manufacturing industry and medical procedures, whilst photonic sensors are indispensable in providing a safer environment.

These examples serve only to illustrate the wider fact that photonics is pervasive in modern life. Whilst specific applications are addressed in the previous chapters contributed by Work Groups 1–5, there are numerous aspects that are generic to a wide range of applications: these are the enablers of our field and accordingly deserve focused attention in their own right. We accordingly emphasise here the development of technologies that have the potential to transform major sectors of our industry.

In order to maximise the benefit to European society, it is vital that European industry is strong at every level, from devices and components through to systems, also embracing manufacturing equipment and methodologies.

Major photonics needs

As has been noted throughout this document, photonic technology is a critical enabler for an extremely broad range of industrial products and services, as well as a vital tool for scientific research across many disciplines. Although the economic impact may be most apparent at the higher levels of the food chain, for example in equipment and services (such as telecommunications, health care and manufacturing using laser tools), experience tells us that competitiveness here is vitally dependent upon access to the most advanced photonics technologies at the component level. Without differentiating technology, truly innovative products will surely be elusive, and, without strong support for discovery and innovation, we cannot achieve strong added-value production. We therefore emphasise the importance of a European supply chain in the strategically important areas of component and systems technology, embracing high-volume manufacturing as well as high-value, specialised components.

In the following text we set out a top-level agenda based on a number of key technical capabilities, including photonic integrated circuit (PIC) integration platforms, advanced semiconductor device technology, electro-optical circuit board technology, new materials, and new technologies such as nanophotonics, which constitute a prerequisite for Europe’s continued ability to innovate in photonics and to be competitive in manufacturing. These capabilities represent key enablers for a vibrant European components and systems industry, able to thrive in global markets and to deliver the socio-economic benefits for Europe.

In addition to stimulating the development of new photonic technologies, it is vital that our programme facilitates the availability of, and access to, these technologies by innovators and entrepreneurs across the EU. We have accordingly identified a number of measures that are designed to ensure that new technology is brought to the marketplace in the most timely manner, managing the risk factors that might prove insuperable for any individual player. Our recommendations include pilot manufacturing capabilities in key constituent technologies, including photonic integrated circuits, integration of photonics with electronics, certain classes of semiconductor devices and...
high-functionality, photonic-enabled electronic systems. In this way, technologies requiring high initial investment may be brought to the point where entrepreneurs can ascertain their true value and take forward the task of building viable and vibrant businesses on established foundations, without taking commercially unacceptable risks.

Involvement of value chain partners
Our vision is of a European industry that is strong at every level, from devices and components through to systems, also embracing manufacturing equipment and methodologies. Accordingly, all members of the value chain need to be fully engaged, from fundamental research in materials through to the users of the systems, in which photonic technologies are deployed.

We perceive major opportunities to build and sustain a vibrant manufacturing industry in Europe based on advanced technology, best-in-class design and innovative manufacturing techniques. In order to achieve this objective, Europe needs to grow and support a photonic eco-system having the critical mass of skills and capabilities, an environment in which photonics and its client industries can advance together. Horizon 2020 provides an important opportunity to develop new design tools and processes, as well as enabling technologies, manufacturing tools and techniques, which will help to ensure that Europe has these skills and capabilities in place. Furthermore it must underpin the education and training of a new generation of technically skilled and innovative people, who can carry out the research, innovation and entrepreneurial activity needed to maintain the forward momentum of our programme.

The fragmentation of European research infrastructure has long been identified as a limiting factor, and the Network of Excellence initiative in Framework 6 was a first attempt to put this right. Certainly the aim of establishing larger virtual research teams and pan-European facilities, thereby absorbing capital cost as well as providing an intellectually stimulating environment, should be a factor in our future policy. It will be necessary to work with existing research and innovation centres to ensure the most efficient coordination of activities and maximum leverage on future investment.

We need to engage all stakeholders in the coordination of these efforts. As noted elsewhere, this will require discussion and partnership with other
industries, including microelectronics, life sciences, ICT and advanced manufacturing. Furthermore, it is vital that we engage and support the full spectrum of industrial players, from SMEs to large manufacturing enterprises.

**Major photonic research & innovation challenges**

Our vision is built on the foundations of world-leading research in focused areas that are relevant to photonics across the board, coupled with initiatives designed to ensure that the resulting technology is put to use in the most efficient and effective manner. We have identified a number of priority areas for investment in generic technologies that will have a high impact across a wide range of applications, thereby complementing the recommendations of the applications-oriented working groups. These relate specifically to the following areas:

- Photonic integration, including the development of generic integration platforms and foundry models, thereby allowing complex linear and nonlinear photonic functionality to be realized in an integrated form
- Integration of photonics with microelectronics at the chip, board and system levels
- Technologies for cost-effective manufacturing of components and subsystems, including automated photonic device assembly and electro-optical circuit board technology
- Semiconductor optical device technology, with particular reference to semiconductor lasers
- Exploitation of new materials, including new semiconductors and nanophotonic materials (for example, metamaterials & plasmonics), multifunctional fibres, and their associated fabrication technologies

Our first recommendation relates to photonic integration. As in microelectronics, many applications can be addressed in a much more compact and cost-effective way by integrating the required functionality in a single chip of III-V semiconductor material (for example, indium phosphide, gallium arsenide), silicon, or dielectric material. As a result of past EU investments, Europe has a very strong position in these technologies. Whilst photonic integration is one of the most important keys to competitive advantage, present ways of working do not unlock its full potential. Not every supplier can be vertically integrated, and access to technologies by smaller companies, for example, SMEs, is currently very limited. Furthermore the large variety of photonic devices and technologies that have been developed is beginning to limit progress in the industry. Europe has taken the lead in developing a new way of working, based on integration technology platforms supported by generic foundry manufacturing, which can provide a step-change in the effectiveness and applicability of Photonic Integrated Circuit (PIC) technology. European initiatives on generic photonic integration have attracted great interest and are beginning to be emulated worldwide, particularly in the USA. It is vital that these initiatives are carried forward in Horizon 2020, so that the most advanced PIC technologies are developed in the most efficient way and made accessible for exploitation to the widest spectrum of end-users. Innovation actions in this area have been specifically identified as a priority by the applications-oriented work groups, especially in Information and Communications technology (Work Group 1).

The generic integration approach has proved highly successful in the microelectronics industry and although the challenges in applying the same methodology to photonics are different and are in some ways greater, we can nevertheless learn from the microelectronics experience. For instance, foundry-access programs, such as MOSIS in the USA, had a pivotal impact in the development of the VLSI industry, not least by training a large number of designers in circuit design techniques, and we therefore recommend that a similar approach should be adopted in Europe for application-specific photonic integrated circuits in silicon
2. Photonics Research and Innovation Challenges

photonics, III-V semiconductors and dielectric and polymer materials. Furthermore, just as in microelectronics, we must invest significant scientific resources in the development and evolution of robust, accurate and efficient simulation and computer aided design (CAD) tools and in process and packaging technologies supporting the generic platform approach. Consideration should also be given to the integration of optical circuit design tools with systems-level simulation tools, in order to facilitate a holistic approach to the development of application-specific products based on PIC technology.

In order to expedite the future evolution of our chosen platforms, we propose research on large-scale integration processes allowing the seamless introduction of new technologies. It is vital that the platforms can embrace new technologies with potential for improvements in functionality, compactness, energy efficiency, manufacturability or cost-effectiveness. Technologies such as photonic circuits based on membranes, nanowires, photonic crystals, metamaterials and plasmonics, including optical antenna structures, should be supported, and opportunities sought to integrate these elements into generic PIC capabilities at the earliest opportunity. In addition, extension to new wavelength ranges (for example, visible, UV) should be addressed. Further advances in manufacturing techniques will certainly also be required, for example, developments in high-volume, high precision, and cost-effective techniques, such as nanoimprint lithography (NIL).

Alongside the development of device and circuit technology, a concerted attack must be made on the challenges of cost-effective manufacturing of components and subsystems. Here we need to deploy European expertise on robotics, automated precision assembly and test technologies to offset the cost advantage of Far-Eastern manufacturers, and ensure that the full value chain can be addressed within Europe. We envisage here a synergistic exploitation of electronic, optical and mechanical technologies in an optimum combination. New structures with improved capacity for heat dissipation and thermal control are essential, as are strategies for managing electromagnetic design challenges. European strengths in hybrid photonic integration, including photonic lightwave circuit technologies, should be exploited, along
Towards 2020 – Photonics driving economic growth in Europe

with developments in new optical elements, such as stacked micro-optics technologies and free-form optical surfaces. The emergence of laser-assisted manufacturing processes and of printing technology for additive deposition of functional materials offers further potential for enhancing competitiveness.

Major opportunities will result from a close coupling of advanced photonics with current trends in microelectronics. For example, we are already seeing the application of powerful digital signal processing in link equalisation for high-speed telecommunications systems (40Gbit/s, 100Gbit/s), as well as in data communications over shorter links. This approach is revolutionising the design of such systems and allowing photonics to reach new levels of performance and cost-effectiveness. Close integration of photonics with electronics is also of major importance for micro-opto-electromechanical systems (MOEMS), sensors and medical devices. It is vital that we accept and embrace the importance of electronics in photonic systems, and work to integrate the photonic and electronic parts very closely in our research and development strategy.

We note that IC manufacturers and processor architects are increasingly looking to photonics to provide the next level of performance in their devices, for instance in providing data links across individual chips, as well as optical interconnects between devices within a given subsystem. Besides improved functional performance, such approaches can also lead to significant improvements in power efficiency. The merging of electronic and photonic technologies at the circuit level will accordingly be a vital area of research. We anticipate that hybrid and heterogeneous integration techniques (for example, 3-dimensional multi-chip modules, III-V layers on active silicon ICs, dielectric/silicon hybrids) will augment the capabilities of photonics based purely on silicon. These advances must be supported by appropriate efforts on device packaging, as well as a holistic approach to integrated systems design.

At the level of building electronic systems incorporating photonic signal distribution and processing, new system integration approaches and manufacturing techniques are required in order to achieve maximum gearing from the photonic infrastructure. We note here electro-optical circuit board (ECOB) techniques and advanced module concepts, such as will be required for next-generation processors, communications and information storage systems. Over the past decade, European research institutes and companies have spearheaded research and development in the field of circuit board embedded optical links solutions employing planar optical waveguides in polymer or glass. Europe must leverage its currently unparalleled expertise in this field towards the development of commercially viable processes for the manufacture of electro-optical circuit boards and modules, thereby securing a global competitive advantage. ECOB technology forms a vital part of the photonic eco-system of tiered optical interconnect solutions outlined in this roadmap. European manufacturers have built up an enviable position in global markets for semiconductor
lasers, ranging from high power GaAs devices for laser-assisted manufacturing, printing and medical uses, to highly compact vertical cavity surface emitting lasers (VCSELs), such as are employed in human interface devices (mouse sensors, tracking devices), data links, data storage and biomedical/sensor applications. We must ensure that this European lead in III-V semiconductor device technology is maintained and strengthened. Research is required not only on the devices themselves, but also with respect to integration with modulators, MEMS devices and electronics, as well as incorporation into the complete electro-optical subsystems. Specific drivers that should be addressed include active imaging (including gesture recognition for human/machine interface and devices for automobile safety), as well as heat-assisted magnetic recording.

Whilst specific aspects of laser and optical system development are covered in the applications-led work packages, we note here the importance of continued improvements in power scaling, efficiency and extension to new wavelengths, including the ultra-violet, green, mid-infrared (>1.5μm) and THz spectral regions, all of which require corresponding developments in materials (semiconductors, glass and crystals), device and manufacturing technology, as well as advances in related optical components. These advances, in discrete as well as integrated form will underpin important applications in industrial manufacturing, printing, medical systems, visualisation, 3D-recognition, and in sensing and spectroscopy for biomedical and security applications, through exploitation of both linear and nonlinear interactions. We note also the need for continuing development in electro-optic transducers, modulators and detectors towards higher speeds and linearity, such as will be needed for Tb/s interconnects, communications and sensor systems involving synergistic digital processing.

Finally, at the most fundamental level, we recommend a continuing focus on emerging technologies based on new materials, semiconductors, metamaterials, nanostructures and plasmonics, as well as multifunctional optical fibres. A large proportion of the most important advances in photonics have been related to the availability of new materials. Nanophotonic materials and structures, as well as heterogeneous combinations of materials (for example, III-V/Si), can provide the basis for unique capabilities, permitting photonic functions with unprecedented performance in terms of size, speed, power dissipation and functionality. Nanofabrication techniques with unique capabilities should be explored, including site-controlled epitaxy and epitaxy on patterned substrates. The potential of organic materials and organic-inorganic combinations should be fully investigated: whilst the role of these materials in OLED devices is discussed in Work Group 4, we envisage here a wider, generic applicability. Nanostructured surfaces can have chemically and biologically active functionality, which will facilitate the development of new sensor devices. Combination of existing and new materials with different functions (i.e. photon generation and saturable absorption) in a single optical fibre or waveguide will push forward the integration of functionalities presently performed by discrete components. Furthermore, these advances must be brought rapidly into use. Europe is performing well in many highly dynamic market areas that demand rapid innovation and the exploitation of disruptive materials and processes. This trend can be supported through coordinated research and the evolution of innovative manufacturing models. To summarise, a lead in the application of new materials and nanostructures in practical devices will underpin significant competitive advantage for European industry.

We emphasise that in order to exploit the advances in research and development in the areas noted above, concerted actions are required to bridge the gap between research and exploitation. In particular, we have identified several areas where pilot production capabilities will be indispensable.
in proving technical capabilities at the appropriate scale, and bringing technologies within reach of entrepreneurial companies in the various application domains. These actions are identified specifically in the following roadmap timeline. This also identifies those areas where the required research, development and innovation actions should be coordinated between Photonics and other KETs, such as micro/nanoelectronics, advanced manufacturing, materials and biotechnology.

**Expected impact for Europe**

As has been noted elsewhere, photonics is one of the most vibrant areas of the European economy. The total world market of optical components and systems was estimated in 2009 to be in the region of €15 billion with growth to more than €30 billion expected by 2015. Given their pivotal importance across a wide range of industries and services, from telecommunications and information systems to healthcare, investment in generic photonic technologies can have a disproportionately large impact. The leverage from advanced component technologies is extremely large: as an example, we may consider that the global market for telecommunications services, at more than €2 trillion, is critically dependent upon the capabilities of its constituent photonic elements. Similar considerations apply in other market sectors. The leading players in communications, laser technologies, lighting and bio-photonics all require innovative optical components as the basis for their differentiation in the marketplace. We should also note that photonics is a strong export industry: the European market of optical components and systems represents about 11% of the total European photonics production, while the European market share in the global market place approaches 50%.

We note also that European manufacturers of production tools for photonics have a commanding position in world markets. In order to sustain this strong position against global competition, it is vital that momentum is maintained in the underpinning technology base.

The measures we propose will benefit small and large industries across Europe, as well as the public at large through the improved services that will be made possible with more advanced photonic technology. We recognise the importance of start-up businesses and SMEs in driving technical and product innovation, and several of the measures that we propose will be of particular benefit to SMEs. For example, the development of photonic integration platforms that can be made available widely through generic foundries should revolutionise access to high technology manufacturing for small companies across Europe.
# 2. Photonics Research and Innovation Challenges

## Roadmap for 2014–2020

We present here a roadmap addressing the following key technological challenges:

<table>
<thead>
<tr>
<th>Technologies and Concepts</th>
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<tr>
<td>■ Next-generation PIC technologies, especially generic technologies, maximising energy efficiency, density and functionality</td>
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<tr>
<td>■ Innovative concepts for active photonics on silicon (including III-V/Si), embracing high-density, micron-scale emitters / modulators compatible with CMOS circuitry</td>
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<td>■ Ultra-high density photonic &amp; photonic/electronic integration technology</td>
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<td>■ Development and evolution of robust, accurate and efficient simulation and computer aided design (CAD) tools, including integration of optical circuit design with system-level simulation</td>
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<td>■ Next-generation assembly technologies facilitating high volume manufacturing of high precision discrete devices and PICs</td>
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<tr>
<td>■ Technologies for electro-optic circuit boards and advanced module concepts, embracing organic/inorganic integration</td>
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<td>■ High power lasers, especially in relation to power scalability, beam quality, thermal management, robustness against environmental conditions</td>
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<td>■ High speed devices, including</td>
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<td>■ Technology for data transfer at 1Tbit/s and beyond at chip level, with high linearity to facilitate analog operation, A-D conversion and digital signal processing</td>
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<td>■ Energy efficient, scalable photonic switching &amp; interconnect</td>
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<td>■ Sources for optical sensors and next generation storage systems (heat assisted magnetic recording)</td>
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<td>■ Materials and structures for new wavelengths and wide tuning range (&gt;100nm); integrated nonlinear devices to extend wavelength coverage; efficient plasmonic devices; precise beam delivery</td>
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<td>■ Concepts for manufacturability for advanced devices (e.g. QCLs, active imaging devices, sources for HAMR), embracing subsystem integration (e.g. transmitter/receiver)</td>
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<tr>
<td>■ New materials for photonics, including advanced semiconductor structures, ceramics, polymers, nonlinear crystals, metal-dielectric interfaces and multifunctional optical fibres/waveguides.</td>
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<td>■ New photonic coatings and functional surfaces, including applications of micro/nanostructuring and surface functionality for bio-applications, along with associated production strategies.</td>
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<tr>
<td>■ The critical innovation-oriented challenge is to create infrastructure for open access to research and pilot manufacturing in critical technology areas, including photonic and electronic/photonic integrated circuits, packaging and assembly, key semiconductor technologies and advanced materials research.</td>
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## Roadmap for 2014–2020

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<tr>
<td><strong>Photonic integrated circuit technology, availability, accessibility</strong></td>
<td>- Develop processes &amp; building blocks towards second generation of generic photonic integration platforms, with emphasis on maximising energy efficiency, along with high density and increased functionality both at building block and at circuit level</td>
<td><strong>Photonic integrated circuit technology, availability, accessibility</strong></td>
<td>- Technology for nanophotonic devices and circuits</td>
<td><strong>Photonic integrated circuit technology, availability, accessibility</strong></td>
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<td><strong>Electronic/photonic integration</strong></td>
<td>- See Cross-KET initiatives below</td>
<td><strong>Electronic/photonic integration</strong></td>
<td>- See Cross-KET initiatives below</td>
<td><strong>Electronic/photonic integration</strong></td>
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<td><strong>Assembly and Packaging</strong></td>
<td>- New concepts for economic packaging and assembly of high performance, high functionality devices and PICs. Development of generic low-cost approaches in packaging, applicable to a broad range of PICs</td>
<td><strong>Assembly and Packaging</strong></td>
<td>- Continuation of programme; establish technology base for innovation actions (see below)</td>
<td><strong>Assembly and Packaging</strong></td>
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<td><strong>Technologies for electro-optic circuit boards and advanced module concepts</strong></td>
<td>- Concept research, fundamental technology development</td>
<td><strong>Technologies for electro-optic circuit boards and advanced module concepts</strong></td>
<td>- Establish manufacturing technology and standards, leading to pilot line actions (see below)</td>
<td><strong>Technologies for electro-optic circuit boards and advanced module concepts</strong></td>
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<td><strong>Note:</strong> RTD actions in assembly and packaging may be cross-KET with Advanced Manufacturing</td>
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### 2. Photonics Research and Innovation Challenges

|------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------|
| **Semiconductor Photonic Devices** | - High power lasers featuring high scalability, beam quality, thermal management, robustness against environmental conditions  
- Technology for 400Gbit/s-1Tbit/s on chip; high linearity; energy efficient, scalable photonic switching & interconnect  
- Source technology for active imaging, sensor and storage solutions (HAMR) | **Semiconductor Photonic Devices** - Continuation of 2014/5 programme |  | **Research actions for the second part of the Framework will follow on from the research of the first four years, taking on board new developments in devices, assembly technologies and materials.** |
| **New materials and functionalities** | - Semiconductor and dielectric materials for enhanced functionality photonic devices, including micro/nanostructuring and plasmonics; multifunctional components (optical fibres and waveguides) | **New materials and functionalities** - Creation of shared infrastructure for research in advanced materials for photonics |  | **Research actions for the second part of the Framework will follow on from the research of the first four years, taking on board new developments in devices, assembly technologies and materials.** |
| **Innovation requirements** | **Photonic integrated circuit technology, availability, accessibility** - Rollout of first-generation generic foundry platforms, building on existing capabilities with additional  | **Photonic integrated circuit technology, availability, accessibility** - Support and develop pilot foundry production capabilities based on first-generation PIC technologies,  | **Photonic integrated circuit technology, availability, accessibility** - Maintain support for 1st generation platform, including access for researchers and SMEs,  | **Photonic integrated circuit technology, availability, accessibility** - Continue to support and develop PIC platforms through an access programme for researchers and SMEs,  |
|-----------|-----------|-----------|------|
| titled investments to establish pilot production facilities.  
- Qualification of first-generation platforms for demanding reliability requirements | with availability to researchers, SMEs and larger enterprises  
- Establish short turn-round time in multiple technologies (InP, Si, PLC)  
- Plan and invest in facilities to facilitate the introduction of second-generation integration platforms with enhanced capabilities including energy efficiency | Qualification of second-generation photonic integration platforms  
- Establish pilot manufacturing of second-generation PIC platforms with availability to researchers, SMEs and larger enterprises | following the successful example of MOSIS in VLSI |

**Note:**  
*Innovation actions in assembly and packaging may be cross-KET with Advanced Manufacturing*

**Note:**  
*Innovation actions in electro-optic circuit boards and advanced modules may be cross-KET with Advanced Manufacturing*

### Electronic/photonic integration platform
- See cross-KET activities below

### Assembly and packaging
- Plan and prepare for pilot manufacturing facilities for discrete devices and PICs, including generic packaging approaches

### Technologies for electro-optic circuit boards and advanced module concepts
- Plan pilot line implementation

### Electronic/photonic integration platform
- See cross-KET activities below

### Assembly and packaging
- Establish pilot for next-generation assembly of high volume, high precision discrete devices and PICs

### Technologies for electro-optic circuit boards and advanced module concepts
- Pilot line roll out 2018

### Electronic/photonic integration platform
- See cross-KET activities below

### Assembly and packaging
- Initiate pilot line operations for high precision, high volume PIC and laser assembly

### Assembly and packaging
- Continue and monitor pilot line operations

### Technologies for electro-optic circuit boards and advanced module concepts
- Continue, monitor and facilitate pilot line operations
## 2. Photonics Research and Innovation Challenges

### Cross-cutting Key Enabling Technologies (KET) proposals

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<tr>
<td>Semiconductor Photonic Devices</td>
<td>**Plan for qualification actions, standardisation, pilot line implementa-</td>
<td>**Manufacturability and qualification for critical semiconductor power</td>
<td>**Open and facilitate pilot line operations</td>
<td>**Continue, monitor and facilitate pilot line actions</td>
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<td>tion in following period</td>
<td>technologies (e.g. QCLs, active imaging, sources for HAMR)</td>
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<td>**Continue dialogue on management of semiconductor materials from product</td>
<td>**Pilot line implementation for specific device technologies of critical</td>
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<td>safety and manufacturing viewpoint, including the REACH initiative</td>
<td>European importance</td>
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<td>Electronic/photonic integration (cross-KET with micro/</td>
<td>**Develop innovative concepts for active photonics on active silicon ICs</td>
<td>**Continued, with aim of establishing platform for generic use in the fol-</td>
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<td>nano-electronics): RTD</td>
<td>(including III-V/Si), with emphasis on high-density, micron-scale emit-</td>
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<td>nano-electronics): RTD</td>
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<td><strong>Electronic/photonic integration platform (cross-KET with micro/nano-electronics): Innovation</strong>&lt;br&gt; ■ Develop current concepts towards open access (performance, compatibility and usability goals)</td>
<td><strong>Electronic/photonic integration platform (cross-KET with micro/nano-electronics): Innovation</strong>&lt;br&gt; ■ Qualify first-generation electronic/photonic platform; establish pilot manufacturing capabilities</td>
<td><strong>Electronic/photonic integration platform (cross-KET with micro/nano-electronics): Innovation</strong>&lt;br&gt; ■ Release first-generation electronic/photonic platform to designers and SMEs through pilot manufacturing lines&lt;br&gt; ■ Qualify second-generation, high functionality, ultra-compact photonics on active CMOS; plan pilot production capabilities</td>
<td><strong>Electronic/photonic integration platform (cross-KET with micro/nano-electronics): Innovation</strong>&lt;br&gt; ■ Introduce pilot lines for second-generation electronic/photonic platforms&lt;br&gt; ■ Sustain access to platforms for researchers, SMEs and larger enterprises</td>
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<td><strong>Cross-KET activities</strong>&lt;br&gt; ■ Device assembly and packaging technologies, including pilot lines and related equipment (Advanced Manufacturing)&lt;br&gt; ■ Electro-optic circuit boards and advanced module concepts (Advanced Manufacturing)&lt;br&gt; ■ Materials and Nanostructuring for photonics (Advanced materials), including shared infrastructure&lt;br&gt; ■ Structural adaptation and bio-active photonic devices (Biotech)</td>
<td><strong>Continued …</strong> Detailed planning in collaboration with KET ETPs</td>
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**Additional candidates for cross-KET programmes**
2.7 Education, Training & Disruptive Research

Main socio-economic challenges addressed

Major progress is needed both on advanced research, and on education and training of highly-skilled workforce, if photonics is to address successfully the major socio-economical challenges facing Europe, ranging from health care to security, from energy saving to efficient and clean industrial production, and from environmental protection to fast and efficient communications.

Indeed, the industrialised world and developing countries alike have to address the problems of sustainability and quality of life, and these will require new approaches and solutions. Photonics, in recognition of its strategic significance and pervasiveness throughout many industrial sectors, has been identified as one of the Key Enabling Technologies for Europe. Not only does advanced photonics research offer new technical solutions for existing problems, but it also paves the way to as yet unimagined applications. The education and training of high-level professionals and a skilled workforce, including technicians, will allow innovation in photonics to be sustained, thus ensuring continued economic growth and employment.

Major photonics needs

Three main photonics fields have been identified that must be addressed by advanced research to tackle the main societal challenges and produce innovative solutions across the sector:

- **Nanophotonics** (including graphene photonics, metamaterials, and plasmonics). These offer enormous improvements in sensing, imaging, and energy generation.
- **Quantum optics and quantum information.** This technology will revolutionise the field of computing, data processing and secure communications, but also has the potential to impact the field of sensing.
- **Extreme light** (including high power, extreme wavelengths and ultra-short pulses). This technology will broaden the application of light-matter interactions, thereby opening up innovative new techniques for sensing, imaging, material characterisation, material processing, and advanced manufacturing, and also playing a major role in fundamental studies.

Achieving these goals requires specific actions in education and training, aimed at addressing three specific target groups – young minds, professionals, and society at large. The main actions identified to address this are:

- outreach towards young minds, the general public and political authorities, aimed both at attracting more students, and at creating a strong consensus and awareness of the importance of photonics.
strengthening the cooperation with industry, both to better match their knowledge and skills needs in third and fourth-level education programs, and to offer life-long learning programs and vocational training.

Involvement of value chain partners
The inherent pervasiveness of photonics and its interdisciplinary nature require the broad involvement of many value chain partners, both as directly cooperating partners for RD&I, and as potential end-users. When dealing with advanced research, it is clear that interaction with all the other Key Enabling Technologies and related platforms will be essential, so as to exploit synergies and achieve higher levels of innovation. In terms of end-users, all industries developing photonic components and systems need end-users to be involved at the earliest stage, to ensure that research roadmaps address their specific needs in terms of properties and functionalities. Present and future societal needs should also be considered when defining medium and long term research goals.

The various value chain partners will each have a role in the education and training system actions:
- primary and high-school teachers need to be involved for effective outreach programs aimed at young students
- science and technology museums have to be targeted to set up exhibitions for the general public
- communication experts and scientific journalists need to participate in communication projects based on conventional and new media
- photonics ‘users’ will provide essential perspective for promoting interdisciplinary education, embracing photonics and its cross-fertilisation with other technologies for new applications
- the technical management and HR of photonics-based or photonics-enabled industries, together with both local and European political authorities, need to be involved in the definition of life-long learning and vocational training programs.
- regional and national clusters will support local smart specialisation strategies.

Major photonics research and innovation challenges
During the preparation of Photonic21’s second strategic research agenda and the photonics vision paper, an extensive analysis has been performed to identify the areas of major potential impact on medium-long term societal challenges and on future European industrial competitiveness, thereby ensuring that advanced research can be defined effectively.

Building on this analysis, the major challenges for research, education and training were identified, and actions defined to be undertaken within Horizon 2020.

Research
Adopting a medium-long term perspective, advanced research must consider as the driving force of future innovation, pushing beyond the currently foreseen applications. A number of critical aspects should be considered:
- Working with industry to identify what new photonics properties and functionalities will be needed to improve present components and systems, that they do not yet know how to achieve. This can be used to construct targeted roadmaps, identifying directions and actions required to achieve specific goals. With many new fields being explored, a wide range of possible solutions must be studied to identify the optimal ones, with greatest potential for industrial applications with acceptable time to market.
- Ensuring that disruptive research is not overlooked. Many new photonics applications currently cannot be predicted, so there must be room for exploring the unexpected.
- An open innovation approach involving the close cooperation between universities, public research institutions and industries is becoming essential in our knowledge-based society, and
will promote greater European competitiveness through advanced research.

- The establishment of open-access distributed high-tech facilities, so as to allow advanced experiments to be performed, new materials to be developed and characterised, and devices and prototypes to be fabricated and tested in the most efficient way.

Details of the roadmap for research in the time frame of 2014-2020 are given in the following table. However, it is useful to identify a number of representative examples of the ‘hot topics’ – clearly valuable developments that as yet cannot be achieved with present technological capabilities, such as:

- Nanoscale imaging
- Low-loss semiconductor photonics
- Semiconductor/other material lasers with higher efficiency or for currently inaccessible wavelengths
- Non-reciprocal semiconductor materials
- New materials for THz
- Optical materials with optimal thermal characteristics
- Single photon sources and detectors operating at room temperature
- Bio-compatible material for artificial retina

Over a longer time-scale, further developments can be considered coming from fundamental science, and based on novel concepts and approaches for materials and processes. These could lead to useful applications, but as yet the specific application need or means of fully exploiting their potential are unknown. Examples falling within this category include:

- Photon-photon and photon-phonon interactions
- Light-matter interaction in ‘extreme’ conditions
- New materials (engineered materials, new organic materials)
- New aspects of photonics at the nanoscale

- Unexplored new material systems (graphene, silicene)

Innovative research should always be developed following guidelines based on its potential impact for making photonics more accessible, eco-friendly, low-cost, or in replacing or reducing use of dangerous or scarce materials.

Education and training

For education and training, one of the most critical challenges will be to overcome the present major difficulty facing the photonics community, namely of securing the necessary knowledgeable and skilled workforce. This shortage applies at all levels, from technical management and R&D positions through to technical staff, and is encountered both in industry and academia.

In the longer term, solving these shortages will require increasing the wider community interest in photonics, and an awareness of its importance.
Towards 2020 – Photonics driving economic growth in Europe

Details are given in the roadmap table, but it is worth highlighting some general aspects:

- coordinated actions will be needed to take full advantage of all possible activities and outreach projects, so as to maximise impact
- specific attention should be devoted to follow-up actions, and the most successful actions should be extended and supported until they can become self-sustainable
- the involvement of non-photonics players (communication experts, school teachers, etc.) will be essential to break down existing barriers within the photonics community
- successful ambassadors should be identified for promoting photonics in the wider community
- cooperation with local and national authorities will be needed to ensure sustainability. Industries and private partners should also be encouraged to support outreach programs
- future young students should be exposed at the earliest opportunity to fascinating programs in photonics (following the examples of Photonics Explorer and Luka’s Land of Discovery)
- establishing awards for innovative students and competitions for teams of young researchers on specific problems
- showcasing photonics exhibitions in all major Science and Technology museums throughout Europe, including interactive experiments suitable for visits of students with their teachers
- ensuring that appropriate attention is devoted to demonstrating the present impact and future innovation potential of photonics, rather than merely presenting an historical perspective
- simpler but fascinating photonics installations provided at high throughput public environments (airports, train stations, commercial malls, etc.)
- photonics events (shows, conferences, dissemination activities) co-located with non-scientific activities (e.g. suitable art or photography exhibitions)
- full use of available mass media (TV, press, internet) for dissemination programs.

All actions should take care to address the gender problem that, despite continuous effort, still faces us with a clear gender unbalance in science and technology.

Clearly outreach is not the only challenge. A wider availability of photonics courses will be needed at the university level, and these must be matched with the development of entrepreneurial skills. A strong interaction with industry will be essential for establishing vocational training and life-long learning, particularly so for SMEs. Local specialisation and its specific needs should be addressed, though wherever possible aiming for a pan-European approach.
## 2. Photonics Research and Innovation Challenges

### Roadmap for 2014–2020

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<tbody>
<tr>
<td>Novel concepts and approaches for materials</td>
<td>Realisation, characterisation</td>
<td>Feasibility</td>
<td>Prototypes</td>
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<tbody>
<tr>
<td>Quantum information: explore new quantum approaches to signal transmission, data processing, and sensing.</td>
<td>Quantum information: realise and characterise quantum-based simple integrated circuits as building blocks of future quantum devices and systems.</td>
<td>Quantum information: realise, characterise and qualify quantum-based integrated devices and systems.</td>
<td>Quantum information: realisation of engineered prototypes based on quantum optics providing new characteristics and functionalities.</td>
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</table>

| Infrastructures and facilities | Define needs for open-access infrastructures and facilities for material development and device fabrication and characterisation; Foster cooperation with existing distributed infrastructures (e.g. LaseLab Europe) and with infrastructures under development (e.g. ELI, Extreme Light Infrastructure). | Realise the needed infrastructures; Strengthen cooperation with existing infrastructures and facilities; Foster cooperation with SMEs on highly innovative projects. | Guarantee open access to infrastructures to both academic institutions, research centres and SMEs throughout time. | Guarantee updating and maintenance of open-access structures. |

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### Table 1: Disruptive Research

- **Nanophotonics**: realise and characterise simple devices based on the new approaches and materials.
- **Quantum information**: realise and characterise quantum-based simple integrated circuits as building blocks of future quantum devices and systems.
- **Extreme light**: realise basic experiments exploiting light-matter interaction in new regimes.
## Innovation requirements

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<tr>
<td>Define guidelines to make photonics more accessible, eco-friendly, low-cost, capable of efficiently address societal challenges and innovation needs, and of replacing dangerous and scarce materials; Involve photonics-based and photonics-enabled industries to define their long-term needs.</td>
<td>Define specific societal challenges and innovation needs to be targeted in health-care, energy production and saving, high-speed communication, environmental protection, safety and security, remote sensing, advanced imaging, e-services, etc.; Define areas of major market potential.</td>
<td>Involve end-users to define long-term innovation needs for smart cities and communities that can be addressed through photonics; Examine time-to market perspectives and market potential.</td>
<td>Involve all industrial players and end-users to bring innovation to production and market exploitation.</td>
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</table>

## Cross-cutting Key Enabling Technologies (KET) issues

| Highly innovative advanced research in photonics has evident synergies with all the other KETs: micro and nanoelectronics (e.g. in photovoltaics); nanotechnology (e.g. in nanophotonics); advanced materials (e.g. in graphene and silicene photonics); biotechnology (e.g. in nanobiophotonics). Advanced manufacturing is also essential. The extent and importance of the possible synergy varies depending on the application field being targeted and the consequent materials and solutions of choice. | Synergies will become deeper and at the same time more specific throughout research evolution towards the realisation of photonic devices and their application. | Hybrid systems employing devices based on photonics and other KETs will be considered to address the innovation needs for smart cities and communities with maximum efficacy. | Synergies of the different KETs will be exploited to address production needs. |
### Roadmap for 2014–2020

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<tr>
<td><strong>Outreach to young minds</strong></td>
<td>Address both kids and secondary school students with specific programs, starting from existing experience (Photonics Explorer, Luka’s land of discovery, etc.); Involve teachers in all programs; Organise summer camps; Create a network of outreach-committed centres (academic institutions, research centres, etc.) to sustain and extend actions.</td>
<td>Extend existing programs to new countries through the involvement of local governments; Involve national and international learned societies for support and help in dissemination; Update and where possible and meaningful extend the content of the programs; Involve all-level students through individual awards and team competitions on dedicated problems; Involve industries for sponsorship of outreach programs and of team competitions on specific problems; Involve Science and Technology museums in outreach programs through permanent interactive exhibitions.</td>
<td>Stabilise outreach programs by making them self-sustainable; Strengthen cooperation with learned societies; Strengthen cooperation with industries.</td>
<td>Reach a pan-European dimension for most successful outreach programs and create suitable structures to ensure maintenance.</td>
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</table>

| **Outreach to general public** | Promote photonics through different media: press, TV, internet, apps, conferences related to art events, etc.; Launch competitions for best videos related to photonics so as to promote direct involvement e.g. of young people (not necessarily studying photonics) | Involve Science and Technology museums to create permanent, interactive exhibitions in photonics (seek for support from companies); Set-up simple but impressive photonics exhibitions in highly crowded environments (such as airports, stations, shopping malls); | Extend successful initiatives, stabilise and maintain them; Involve all possible private and public partners that can make initiatives self-sustainable | Reach a pan-European dissemination of the most successful initiatives |

Table 2: Education and Training
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<tr>
<td><strong>Specific programs for technicians (high school; BoSc; vocational training)</strong></td>
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<td>Promote local initiatives on special occasions (companies open day, etc.); Promote photonics participation in any local or international initiatives such as day of science &amp; technology; Identify ambassadors for photonics; Set-up photonics-related shows and documentaries.</td>
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<tr>
<td><strong>High level education (university &amp; PhD)</strong></td>
<td></td>
<td>Organise courses mainly targeting SME needs on a local basis; Support smart specialisation initiatives; Involve national and international structures (education and outreach-oriented networks, learned societies, etc.) to exchange best-practice and provide support to extend programs beyond the local level.</td>
<td>Support best initiatives to make them self-sustainable so as to guarantee stability in time.</td>
<td>Support spreading of best initiatives throughout Europe, where needed, while respecting local specificity.</td>
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</table>
2. Photonics Research and Innovation Challenges

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<th>Actions for the implementation of the roadmap</th>
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<tr>
<td>The experience of 7th Framework Program highlighted some critical issues that need to be addressed for a successful implementation of the future roadmaps, both for disruptive research and for education and training.</td>
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</table>

**Disruptive Research**
Disruptive research is an essential part of the Excellent Science pillar of Horizon 2020. Funding programs should consider the high-risk aspect intrinsic to really disruptive research, together with the importance of having open schemes to help achieve real breakthrough results.

**1. Future Emerging Technologies**
The FET scheme has already proved to be successful and sufficient. However, some actions could be undertaken to increase its impact within the photonics area. In particular:

- **FET-Open:** Although the adopted fully bottom up approach precludes the introduction of specific topics, it is strongly recommend that the European Commission:
  - raises the number of photonics professionals in the evaluation committee
  - communicates and disseminates photonics related FET Open projects as success stories

- **FET-Proactive:** It is recommended that DG Connect introduces photonics related topics.

**Lifelong learning**

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<td>Support innovation awards; Foster interdisciplinary education including photonics, and cross-fertilisation towards applications; Foster exchange of information to support contacts between students and industries.</td>
<td>Corporate members, etc.) and industrial partners to favour contacts between students and industries.</td>
<td>Organise courses mainly targeting SME needs on a local basis; Support smart specialisation initiatives; Involve national and international structures (education and outreach-oriented networks, learned societies, etc.) to exchange best-practice and provide support to extend programs beyond the local level.</td>
<td>Support best initiatives to make them self-sustainable so as to guarantee stability in time.</td>
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</table>
FET Flagships: Photonics is already key in some of the FET Flagships projects, hence it is recommended that this activity could be used to enhance communication and dissemination of FET Flagships through attractive ways of communication, audio-visual, etc. A good visibility of successful photonics projects will foster further actions in the field.

2. ERC grants
ERC grants are traditionally devoted to funding projects of scientific excellence. Although quantum electronics and optics related research have been funded in the past, the scientific excellence underlying photonics technologies seems to have been underestimated. Although specific topics cannot be introduced in the fully bottom up ERC research programme, it is recommended that the European Commission:

- raises the number of photonics professionals in the evaluation committees of the Physical Sciences and Engineering Panel
- communicates and disseminates photonics related ERC Grantees and their projects as success stories

3. Access to Research Infrastructure

This aspect is fundamental for research institutions and universities to promote mobility of researchers and to ensure efficient usage of facilities. Although ESFRI infrastructures will have a priority under this activity, it is recommended that the Commission facilitates this support through other forms of alliances or networks of research facilities & infrastructures, both specific to photonics and to KETs in general.

Education and Training
Past experience has demonstrated that implementation of successful and effective actions to promote photonics in education and training has been difficult and challenging. In addition to the above recommendations reported, the following aspects should be considered:

1. Outreach

- Exhibitions and shows: Exhibitions and shows, fairs and festivals each provide an effective opportunity for the wider popularisation of photonics to the society, and need to be enhanced and provided at a European level. Strategic alliances with committed members allow for the design and implementation of activities, fostering a wide participation from other stakeholders. Connections should be established with existing networks and programs (for example, ECSITE, PLACES, NetS-EU). The involvement of the Commission will be essential for the identification, enabling and evaluation of the actions.
- ‘Living Lab’ and ‘Fab Lab’: Two new concepts are ‘Living Labs’, allowing some experiments to be performed by visitors under suitable supervision, and ‘Fab Labs’, allowing tools to be assembled and used by visitors to build some simple prototypes. These should be exploited by Science and Technology museums (and possibly...
2. Photonics Research and Innovation Challenges

by academic/research institutions when offering access to the public) as a means of providing a deeper understanding of the technology, and enabling a better knowledge of recent photonics innovations.

- **Prizes:** Different prize awarding models should be considered for motivating students:
  - Teams of youngsters competing in games and competitions on specific topics of industrial relevance, held at a European level and organised by suitable stakeholders.
  - Individual prizes following the example of the existing 'Student Innovation Award' promoted by Photonics21.
  - Individual or group prizes for activities related to the promotion and dissemination of photonics (possibly also related to non-photonics events, such as art shows, etc.).
  - Individual or group prizes for secondary school teachers in recognition of their commitment to photonics related activities.

2. Higher Education

The European Commission has recently launched a High Level Group on the Modernisation of Higher Education. It is recommended that a strong participation of the photonics community within such a group should be considered, both to bring its experience and to make sure that photonics related issues and needs are taken into account, particularly since these needs will be common to all Science and Technology topics, and in particular to KETs.

3. Mobility of students and young researchers

It is recommended that the Commission increases the number of photonics professionals participating in the evaluation committees of all-level mobility programs, such as Erasmus and Marie Curie actions. It is also recommended that the Commission communicates and disseminates photonics related projects that already exist under different schemes.

4. Lifelong learning/Vocational training

Several universities, research centres and private companies are already active in offering training and short courses (the latter mainly in connection with large conferences/technical exhibitions) for professionals at all levels, from technicians to R&D and business managers. An effort should be made to create a database of existing modules,
so as to define what is already available and what is missing, what can be extended to a European level, and what needs to be addressed on a local basis. This will allow the urgent needs of photonics industry to be addressed through immediate real-time actions.

**Expected impact for Europe**

In our knowledge-based society, no real and long-lasting innovation is possible without advanced research to create the basis for future development, and without a wide class of knowledgeable, skilled and well-trained workers, able to sustain continuous improvement and efficient production in both science and technology.

The research areas that have been identified as priorities and now being tackled are likely to revolutionise the field of photonics, bringing new solutions and innovative approaches to address the most difficult of challenges faced in many areas.

The need for sustainable development and a better quality of life requires a green economy, energy efficiency and saving, extended healthcare, safety and security, improved communication, quality and sustainable production, open innovation, environmental care, cultural heritage preservation, etc.. New trends developing in photonics could have a substantial impact in all these fields, including:

- **Nanophotonics.** Through the development of new and nanoengineered materials with extended optical properties and unprecedented functionalities, nanophotonics offers solutions to many challenges:
  - energy efficiency, through the development of new solutions for photovoltaics, and energy saving, through the realisation of new highly efficient light sources
  - healthcare, through the realisation of smaller functionalised optofluidic lab-on-chips for point-of-care diagnosis, through nanoimaging techniques for advanced diagnostic systems, and by contributing to nanomedicine for example with photoactivated nanoparticles for therapeutic applications
  - safety and security, through the realisation of nanosensors

- **Quantum optics and quantum information** address the problems related to the management of vast amounts of data, and to secure communications with completely new approaches exploiting the laws of quantum physics. Feasibility demonstrations have already been achieved, but many technical challenges are still to be solved in terms of adequate light sources and complex quantum circuits, before quantum computers, quantum communication systems, and quantum sensing can become part of everyday life. However, the achievement of such goals would be a major breakthrough for a future digital society.

- **Extreme light** is expected to open new perspectives in light-matter interactions. The availability of light sources with unprecedented high power, operating in previously unavailable wavelengths and pulse durations will allow the study of materials and processes in unexplored regimes, thus allowing new fundamental knowledge
to be developed. Moreover, it will allow major breakthroughs in many applications, such as advanced manufacturing, safety and security, bio-medicine, chemistry, cultural heritage, etc.

Improved education and training offers the following impacts:

- making photonics a popular topic and thus attracting a large number of students will ensure the availability of a future skilled workforce, without which any other efforts would be unsustainable
- extending the presence of photonics-based curricula and of photonics modules within other curricula will contribute to a broadening of the available workforce
- establishing programs for vocational training and life-long learning, primarily targeting the local needs of SMEs, will contribute to a strengthening of European SMEs.

In conclusion, the above actions targeting outreach, education and training at all levels will all have a major impact on European industrial competitiveness, fostering highly innovative SMEs, and ultimately ensuring the continuing success of photonics with the consequent benefits for economic growth and employment.
Expected Impact of a Photonics PPP

The overall objective of a Photonics PPP is the establishment of a more competitive photonics sector in Europe. This will be brought about through the following individual areas of impact:

- A Photonics PPP will foster photonics manufacturing, job and wealth creation in Europe through a long term investment commitment by both industry and the European Commission.

- It will pool public and private resources to provide more effective and successful solutions for the major societal challenges facing Europe, in particular for healthcare, the aging society, food safety, security, & energy efficiency.

- Accelerating Europe’s innovation process and time to market by addressing the full innovation chain in a number of market sectors where European photonics industry is particularly strong (e.g. lighting, medical photonics, and optical components & systems).

- It will be instrumental in achieving the critical mass necessary for developing a coherent application oriented and market needs driven technology & innovation process.

- Developing and implementing an integrated RDI programme that fully meets the needs and priorities of markets, and tackles the ‘valley of death’ problem by undertaking strategic projects. Such a strengthened RDI capability will impact the full value chain, from research to manufacturing, and from materials to own-equipment manufacturers & end users.

- Integrating the full value chain into an open innovation approach, ensuring early and meaningful end user involvement from concept to manufacture. The early application of such an interactive value creation process will integrate timely market feedback within a common development process, and thereby help avoid poorly conceived products reaching the market.

- Providing the vehicle for the broader involvement of critical organisations outside of the immediate value chain, including other relevant ETPs & PPPs, capital providers, such as the European Investment Bank and Venture Capitalists.
Reinforcing links between Photonics clusters in Europe and their respective regional industry and public authorities to align priorities, streamline efforts, and enable smart specialisation and growth in European regions.

A Photonics PPP will grow photonics manufacturing in Europe thereby creating further ‘high skill’ employment. This will be achieved by enabling the photonics products themselves to be manufactured in Europe, and by ensuring the ongoing competitiveness of other key photonics-dependent manufacturing sectors in Europe.

A Photonics PPP will result in further photonics solutions for the societal challenges of Europe and will have a direct impact on specific industrial sectors:

**Photonics leverages industrial manufacturing**
The laser processing industry on its own is a multi-billion Euro industry, and it also has a substantial leverage effect on many other industries, most notably in the European automotive sector.

**Lighting solutions foster energy-efficiency**
The application of digital lighting solutions would result in annual savings approaching €300 billion of the global energy bill, and savings of 1000 million tonnes of global CO₂ emissions per year.

**Photonics drives huge OLAE market growth**
Growth of the overall OLAE market will rise from its present value of €1 billion to greater than €100 billion.

**Major CO₂ emissions savings through virtual presence**
Display-enabled rich visual communication for virtual presence could dramatically reduce travel for meetings, resulting in a 20% reduction in business trips in Europe alone, potentially saving 22 million tonnes of CO₂ emissions per year.

**Photonic technologies result in advanced visual displays**
Global sales of advanced 3D displays will reach €10 billion by 2021, with a 35% share expected for European companies.

**Photonic technologies drive healthcare**
Photonic technologies could provide a potential 20% cost reduction in healthcare expenditures associated with the demographic changes anticipated in Europe.

**Photonic sensors increase food safety**
The WHO estimates that annually more than two billion illnesses and the deaths of more than two million children are caused by unsafe food, a major reason for this is the absence of a low-cost yet reliable non-contact sensor technology to detect food-borne health threats.

**ICT speeds up the knowledge society**
Photonic technologies leverage a telecommunication infrastructure market worth €350 billion and impact more than 700,000 jobs in Europe.

**Expansion of the photonics components and systems markets**
The European market share for optical components and systems in the global market place is nearing 50%, and continues to grow steadily.

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24 Photonics21 Strategic Research Agenda Lighting the way ahead, page 110
26 The Leverage Effect of Photonics Technologies: the European Perspective, Photonics21
Appendix

The Photonics Multiannual Strategic Roadmapping Process

The Photonics Strategic Multiannual Roadmap was jointly developed and adopted by the members of the European Technology Platform Photonics21, which represents the European photonics community. The photonics roadmapping process was launched at the Photonics21 Annual Meeting 2012 in Brussels on the 27th–28th March 2012, and was continued over that year through workshop meetings and open consultation via the Photonics21 website, leading to its publication in April 2013.

The chapters from each Work Group outline their individual roadmap for photonics research & innovation in each of the different photonics application fields addressed by Photonics21:

- Information & Communication
- Industrial Manufacturing & Quality
- Life Science & Health
- Emerging Lighting, Electronics & Displays
- Security, Metrology & Sensors
- Design & Manufacturing of Components & Systems
- Research, Education & Training

The topics and research areas addressed in this photonics roadmap have been selected and discussed by the more than 300 photonics experts attending the seven Photonics21 workshops held during the Photonics21 Annual Meeting 2012. A further seven Photonics21 follow-up workshops have been conducted during June - September 2012 to further elaborate and finalise the photonics roadmap.
Communication about the photonics roadmap process

The planning and coordination of the overall photonics roadmapping process was performed by the Photonics21 Secretariat. As part of this process, the Photonics21 Secretariat circulated information on the roadmapping process and workshop events throughout the photonics community. Wide dissemination was achieved using the Photonics21 newsletter and information e-mails, the news & events section and member area of the Photonics21 website (www.photonics21.org), and the recently launched Photonics21 Twitter Channel (https://twitter.com/Photonics21).
Interactive workshops & roadmapping process
An interactive workshop concept was adopted for the Photonics21 workshops at the Photonics21 Annual Meeting and follow-up workshops. In these, participants were invited to provide their input and views, which were then discussed, eventually leading to consensus on each Photonics Strategic Multiannual Roadmap section.

Prior to the workshops, the Photonics21 Secretariat had provided all Photonics21 work group members with relevant preparatory material for the photonics roadmapping process.

Figures illustrating the preparatory material for the photonics roadmap process. © Photonics21
Figures illustrating the preparatory material for the photonics roadmap process. © Photonics21
### 4. Appendix

Figures illustrating the plan for Photonics21 roadmap documents. © Photonics21

#### Draft structure - Photonics21 Strategic Multiannual Roadmap

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<td><strong>Introduction</strong></td>
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<tr>
<td>Strategic Objectives and Vision</td>
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<tr>
<td>Key Performance Indicators</td>
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<tr>
<td>The Roadmapping Process</td>
<td></td>
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<tr>
<td>Photonics innovation ecosystems in Europe</td>
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<tr>
<td>(Industry, Research organisations, Clusters, NTPs, etc.)</td>
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<tr>
<td><strong>Photonics Research and Innovation Challenges</strong></td>
<td>(~42 pages)</td>
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<tr>
<td>Information &amp; Communication</td>
<td>(~6 pages)</td>
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<tr>
<td>Industrial Manufacturing &amp; Quality</td>
<td>(~6 pages)</td>
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<td>Life Science &amp; Health</td>
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<tr>
<td>Design and Manufacturing of Componenta &amp; Systems</td>
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<tr>
<td>Education, Training &amp; Disruptive Research</td>
<td>(~6 pages)</td>
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<tr>
<td><strong>Expected Impact of a Photonics PPP</strong></td>
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<tr>
<td><strong>Annex</strong></td>
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#### Draft structure - Work Group 1 chapter

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<td><strong>Photonics Research and Innovation Challenges</strong></td>
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<tr>
<td>Information &amp; Communication</td>
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<tr>
<td><strong>Main socio-economic challenges addressed</strong></td>
<td>(~0.5 page)</td>
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<tr>
<td><strong>Major photonics needs</strong></td>
<td>(~0.5 page)</td>
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<tr>
<td><strong>Involvement of value chain partners</strong></td>
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<td>(outside Photonics industry/research)</td>
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<tr>
<td><strong>Major photonics research &amp; innovation challenges</strong></td>
<td>(~2 pages)</td>
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<tr>
<td><strong>Roadmap for 2014 – 2020</strong></td>
<td>(~1.5 pages)</td>
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<tr>
<td><strong>Expected impact for Europe</strong></td>
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The development of the photonics roadmap drew extensively on the following two Photonics21 strategy documents, each outlining future European photonics research and innovation challenges:

- **Lighting the way ahead**
  - the Second Strategic Research Agenda for Photonics, (Jan 2010)

- **Photonics – Our Vision for a Key Enabling Technology of Europe**
  - the Photonics21 Vision Document, (May 2011)

The Photonics Strategic Multiannual Roadmap builds on these documents to identify research and innovation areas and priorities for the coming years, and it will serve as the strategic reference document for the Photonics PPP in the new Framework Programme Horizon 2020.

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**Development of the photonics roadmap**

Following the Photonics21 workshops, each work group chair set up an editorial group that was responsible for providing a first draft of the work group specific roadmap chapter. These draft chapters were then circulated to the individual Photonics21 work group members for further comments and feedback. Additionally, all relevant materials for the photonics roadmap process were uploaded onto the members’ area on the Photonics21 website. This area is accessible to all Photonics21 members, thereby ensuring an open and transparent process for roadmap definition.

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### Draft structure Work Group 1 Proposed roadmap for 2014 - 2020

<table>
<thead>
<tr>
<th>Critical path from science to market</th>
<th>Novel concepts &amp; approaches for components and systems</th>
<th>Realization, characterization &amp; demonstration of novel components</th>
<th>System design, integration &amp; verification</th>
<th>Demonstration &amp; application of complete system solutions</th>
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</thead>
</table>

**Technological challenges**

- Research actions (Which solutions should be investigated?)
- Innovation requirements (Instruments), Pilot & demonstration actions; Value chain and end users to involve; Market potential; Appropriate innovation models (open, social innovation)
- Cross-cutting Key Enabling Technologies (KET) issues
- Pilot & demonstration Actions; Outline synergies with the other KETs

Figures illustrating the plan for Photonics21 roadmap documents. © Photonics21
Photonics21
Executive Board Members,
Board of Stakeholder Members
and Work Group Co-Chairs