Europe's age of light!

How photonics will power growth and innovation

PHOTONICS21

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Contents

Preface

The Horizon2020 Photonics Public-Private Partnership (PPP) was created to build on the strengths of the European photonics sector and reinforce its competitiveness. For this purpose, the European Commission joined forces with the photonics industry – represented by Photonics21 – and the research community. The result has been a dynamic and effective partnership recognised as the best PPP in Horizon2020 by the Commission's independent evaluators, and as demonstrated by the PPP's impact on jobs and growth in Europe.
We stand on the threshold of a new era: We are even now moving from the age of electronics to the age of photonics. The opportunities and challenges of digital transformation are all around us, compelling us to act. Europe's competitors are not standing still, however, and there is no room for complacency. The years ahead will show whether Europe will lead or lag behind in the coming revolution. The new Framework Programme (FP9) will play an essential role in Europe's digital transformation.

Photonics will be at the very heart of this transformation, providing tools and solutions to literally every industry in every region in Europe that takes up the challenge to become more competitive.
In designing a new strategy for European photonics, we have built on the Photonics PPP's proven collaborative approach. We consulted with the photonics community, including more than 1,700 companies and research organisations. In a series of workshops with participants from both photonics and end-user sectors, we then mapped out our journey forward. The result is a vision for the future of photonics in Europe: a vision for the age of light.

Aldo Kamper
CEO Osram Opto Semiconductors GmbH
President Photonics21

Executive summary

Europe stands on the threshold of a technological revolution: harnessing the power of light to solve our greatest global challenges. Photonics – the science of creating, manipulating, transmitting and detecting light – is literally everywhere, from smartphone displays to fibre-optic broadband to energy-saving LED lights to the laser surgery that saves our life. As light particles (known as photons) replace electrons in many of our most important technologies, innovations already in the pipeline will improve healthcare, grow food, save energy, cut pollution, expand connectivity, transform manufacturing and usher in a new era of mobility. All across the economy, photonics technology will protect jobs and drive growth

Europe's highly dynamic photonics industry is already the world's innovation and market leader in many of the products and services that will power the digital economy of the 21st century. Some 5,000 technology-intensive companies (many of them SMEs) directly employ over 300,000 people. A global market share of 15.5% leaves Europe second only to China. Photonics is a fiercely competitive global market that was worth EUR 447 billion in 2015 and is growing by 6.2% per year. Tripling annual European production to more than EUR 200 billion by 2030 is realistic – provided we can stay at the forefront of photonics innovation.

The European photonics industry is rising to this challenge by investing strongly in innovation: over 10% of the sector's revenues is spent on R&D. Established European photonics clusters link companies with universities, research facilities and public-sector actors across disciplines, industrial sectors and countries. And in the shape of Photonics21, the industry and research community has a strong European platform of stakeholders with a proven track record of collaborating within this sector.

Joint action by the European Commission, the member states and the photonics industry will clear the way to future innovation. But this will require a concerted public-private effort that pools Europe's strengths in photonics and builds out a highly innovative transnational ecosystem. To achieve these goals, a range of specific measures will be needed.

The most important priorities are:

1. **Create and implement a European strategy for photonics leadership** that focuses on mission-oriented breakthrough innovations and large-scale collaborative projects across industries and sectors. A coordinated strategy involving all public and private stakeholders will create the momentum and unleash the broad spill-over effects needed to address global challenges, exploit future markets and create jobs in Europe. As a foundation for future innovation, basic science and research infrastructure should be integrated in this strategic roadmap.

2. **Build a truly European lab-to-fab infrastructure** for accelerating innovation and competitiveness. Europe needs to speed up the uptake of technology and its translation into new products and services. Europe is strong on mastering photonics technologies, so we need to continue building on this strength in order to create disruptive new products and market opportunities. The further buildout of prototyping services and manufacturing pilot lines would help SMEs across Europe to speed up their innovation processes, as would shared assets in research and manufacturing. At the same time, EU and national R&D programs should have a sharper focus on prototyping and market entry.

3. **Boost opportunities for entrepreneurship** in the photonics sector. Access to risk finance must be improved by establishing a Europe-wide fund for photonics start-up, growth and bridge capital. This could take the form of public matching funds that incentivise and leverage private venture capital.

4. **Educate and train tomorrow's specialists** today. Measures should include a coordinated public-private plan to define skill sets and curricula for professions in photonics. The harnessing of light should be a flagship science in schools, universities and across the education system.

If Europe is to translate today's mastery of key technologies into future leadership in a fast-growing global market, further challenges remain to be overcome. Some priorities already on Europe's agenda – such as the buildout of broadband and 5G

connectivity – have a disproportionate effect on demand for photonics. Smart and balanced regulation would both ease and accelerate the rollout of disruptive new products and services.

Finally, Europe must complete the Digital Single Market to establish its leadership in the digital economy and make sure that the photonics revolution can realise its full potential to the benefit of all European citizens.

This report lays out our vision for the future of the photonics sector in Europe and outlines a number of critical missions and steps to turn this vision into reality.

Our mission

European leadership in photonics will deliver these benefits by 2030:

- **Instant diagnosis of major diseases**
  In 2030, healthcare will be fast, precise and cost-effective. Advanced diagnostics, pervasive monitoring and innovative e-health applications will be able to detect body signals, symptoms and diseases early on. Treatment will be highly targeted, minimally invasive and increasingly effective, reducing disability and mortality from cancer, strokes and other major diseases. Diagnosis and treatment will be delivered instantly at the point of care, thanks to the new science of "theranostics." With the help of these and other innovations, Europe will keep an ageing population healthy and fit.

- **Quality food from farm to fork**
  In 2030, we will have the technology to feed the world, push back food-borne illness and reduce the environmental footprint of agriculture, fisheries and aquaculture. Photonics will help supply safe, nutritious and affordable food for all and establish a sustainable value chain from farm to fork. By using ever more precise sensors and measuring devices, farmers, food processors and ordinary consumers will be able to monitor and certify the safety, quality, content and even the origin of food – anytime and anywhere.

- **Accident and congestion-free road transport**
  In 2030, our mobility will be based on multimodal transport. Driving will be automated, connected and electric to maximise safety, efficiency and comfort. Photonics provides essential components, systems and production tools for all aspects of connected mobility, from driver assistance and traffic monitoring to photonics-based IT and telecommunications.

- **A truly circular economy**
  In 2030, Europe's economy will be cleaner, greener and far along its path towards decarbonisation. Photonics technology will help put an end to the depletion of resources by managing material streams in a circular economy, reducing energy consumption in buildings and public spaces, creating efficient industrial processes, developing the next generation of photovoltaics, enabling smart mobility and monitoring our environment in real time.

- **A million new jobs**
  In 2030, European factories will be fast, green and flexible. Photonics technology, including lasers, sensors and 3D displays, will revolutionise industrial production and working environments, making manufacturing more innovative, cost-competitive and resource-efficient. A fully digital value chain from supplier to customer will birth new forms of collaboration and customisation, new services and new business models – all of which will strengthen Europe's industrial base.

- **10% higher productivity**
  By 2030, digital connectivity will create an entirely new quality of urban life. Photonics technology, including lighting, sensors and optical IT, will supply the infrastructure for smart homes and thriving cities, thereby enabling us to live and work in attractive, secure and productive environments tailored to our individual needs.

- **Zero downtime in a terabit economy**
  In 2030, our societies and economies will be fully digital. To make our digital society work and to safeguard trust, comfort and privacy, photonics is the key tool for delivering the necessary performance, resilience and security in data services and network infrastructures. To handle vastly greater flows of data, IT systems will be much more powerful than today while using less energy, thanks to the emerging shift to high-performance optical and quantum computing.

- **Photonics as a flagship science for innovation**
  In 2030, photonics will be a pillar and driver of the knowledge society, playing an instrumental role in the creation and dissemination of knowledge and ideas. At the same time, educators, students, governments, companies and ordinary citizens across all disciplines and sectors will be increasingly aware of the opportunities and potential inherent in utilising light for the benefit of humankind.

Europe is the world's 2nd largest producer of photonics products

European photonics at a glance

Investment

Nearly **€10Bn** – In 2015 European Photonics Industry pledged €9.6Bn to Innovation (R&D spending and Capex)

R&D intensity in the Photonics industry amounts to nearly **10%**

Photonics industry is leveraging public investment in the PPP projects by a factor of **4.3**

Industry participation in Horizon 2020 PP projects increased to **45%** compared to 35% in FP7

7 Prototyping and Pilot Manufacturing services to help end user industry to speed up product development

€49M invested by the EC in the PPP Pilot manufacturing services (Pilot lines)

67 projects started so far under the frame of Horizon 2020 with a public investment of a total of **€278M** EC funding over the first 3 years of Horizon 2020: 2014-2016

Market

The European Photonics market amounts to **€69Bn** per annum

European Photonics Production has increased by over **62%** over the last 10 years

The European Photonics Production has grown with an average CAGR of **5%** since 2005

European Photonics Production Growth rate is more than **3.5** higher than EU GDP Growth rate

50% global market share for European Photonics for Production Technology

35% global market share for European Photonics for Optical Measurement & Image Processing

32% global market share for European Photonics for Optical Components and Systems

Global Photonics Industry grew from **€228Bn** in 2005 to **€447Bn** in 2015

Global Photonics market expected to amount to **€615Bn** in 2020

The photonics sector is **growing twice as fast** as the global GDP

People

19,000 new jobs created in the European Photonics Industry

Forecast: **42,000** new jobs could be created by 2020

9 PPP Projects explicitly devoted to promoting Research, Education & Training in Photonics

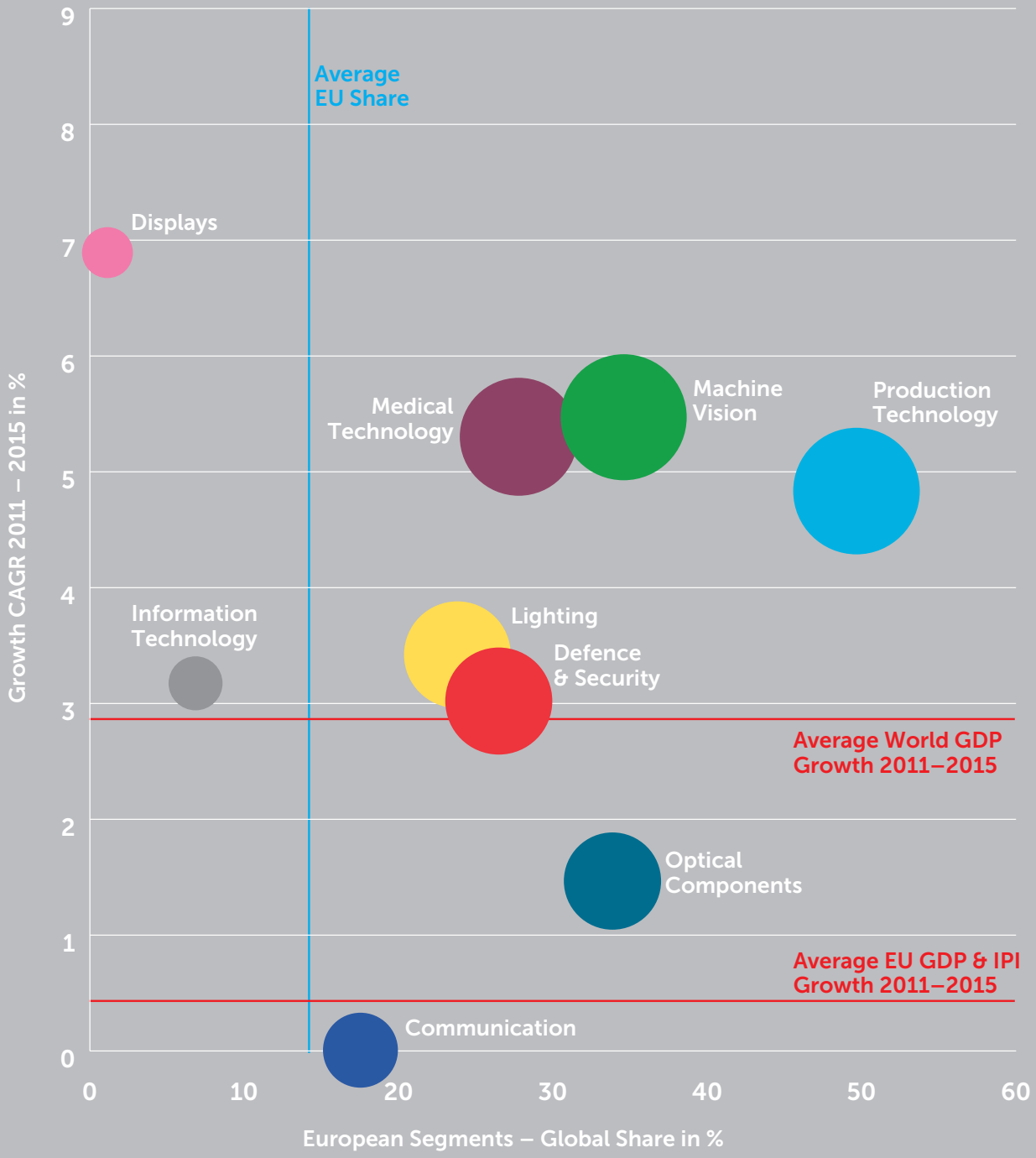
More than **1700** Photonics companies and research organisations back the Photonics PPP.

More than **3000** registered personal members in the platform Photonics21

About **1000** attendees in Photonics PPP strategy development workshops and meetings

Around **300,000 people** in Europe are employed directly in the photonics sector

Global leadership position in European core photonics segments



Source: Optech Consulting Market Research Study 24.1.2017

Europe's bright future in photonics

A mission-critical challenge

Technological innovation is never an end in itself: It is born of the desire to make sure Europe's citizens remain safe, healthy and prosperous. In economic terms, that means working to create future markets today and ensuring that European companies thrive amid fierce global competition. In societal terms, it means equipping our citizens with the knowledge they need to contribute to innovation and make wise use of technology.

Perhaps most importantly, the guiding mission of all our innovation projects must be to meet the major global challenges of our times – including how to adjust to rapid digitisation and urbanisation, how to create a fair and inclusive society, how to keep an ageing population healthy and productive, and how to make efficient use of resources while keeping our oceans clean and our climate safe.

Photonics is at the heart of Europe's efforts to address these challenges. Ever since the development of the laser in the 1960s and of fibre optics in the 1970s, innovative technologies that create, manipulate, sense or otherwise harness light have been deployed in nearly every realm of human activity. Photonics is literally everywhere: Whenever we look at our smartphone's LCD or OLED display, turn on our energy-efficient new LED lamp, watch a movie over an ultra-fast fibre-optic connection or go to the doctor for an endoscopic procedure, we are already using photonics.

What the future holds is even more fascinating, however. Photonics is at the core of a transition in computing technology that will see ever more traditional silicon circuits make way for optical computing, whereby light particles ("photons") replace electrons in running our digital machines. Light-transmitting circuits will enable significant advances in computing speed, making entirely new digital services possible. In medicine, photonics is opening up new opportunities for the treatment of cancer, brain disease and many other conditions using light-activated drug molecules that attach themselves to unhealthy cells. Self-driving cars, drones and humanoid robots will use the next generation of optical sensors to interact safely and intelligently with ourselves and our environment. These and countless other photonics-based innovations will fundamentally change the way we live, work and play.

Europe is already at the centre of this technological revolution. Our universities and research laboratories have produced many of the most promising recent advances in photonics science. Our highly dynamic photonics industry is the world's innovation and market leader in countless products and services that will power the digital economy of the 21st century. The European photonics sector recently overtook Japan's to become the world's number two in terms of global market share, after China.

To capitalise on this strong position and keep the future of photonics safely in European hands despite China's rapid ascension of the innovation ladder, there are still considerable investments to make and obstacles to overcome. While the photonics sector already spends 10% of revenues on R&D, Europe could do still better in more quickly turning research breakthroughs at its universities and research labs into new products and services. Private and public capital could be mobilised more effectively and interdisciplinary ecosystems strengthened. Some crucial regulatory hurdles, too, remain to be overcome. In all these cases, the European Commission, with its overarching approach and transnational perspective, can play a major role.

This report lays out our vision for the future of the photonics sector in Europe and outlines a number of critical missions and steps to turn this vision into reality.

The power of light: fast, precise and clean

Photonics is the technology of harnessing light to benefit humankind. The field encompasses technologies that generate, detect, measure, transmit and manage light, from infrared through the visible spectrum to x-rays. The word is derived from the photon – a particle of light – just as the word electronics derives from the electron.

Light is fast, precise and clean – three unique and highly useful properties that make photonics suitable for an almost limitless array of applications. Photonics technology is used in healthcare and life sciences, energy and lighting, industrial manufacturing, farming and food production, as well as in security and safety, mobility and IT, building on a common scientific and technological basis across all these disciplines. Photonics drives innovation in the economy, helps resolve societal challenges and improves people's lives.

Photonics is also a cross-disciplinary technology, involving physicists, chemists and engineers, as well as application developers in such fields as materials science, biology and medicine.

Technologies already in widespread use today include industrial and medical lasers, optical sensing and diagnostic tools at the micro and nano levels, 3D imaging and holography, lighting and display technology (including new organic LEDs, or OLEDs), fibre optics and photovoltaics. And new technologies and applications are constantly emerging – one example being photonic integrated circuits for use in computing, precision manufacturing and a fast-growing array of medical applications. The future possibilities are boundless, and it is becoming increasingly apparent that, just as the 20th century was the age of the electron, the 21st century will be the era of the photon.

Pushing boundaries: the European photonics platform

To accelerate the sector's development, coordinate resources across disciplines and national boundaries and help define an EU-wide innovation agenda, key stakeholders in European photonics founded the Photonics21 platform in 2005. From 250 members in the first year, the network has grown to over 3,300 members representing 1,700 affiliates. These include universities and other research institutions, industry associations, government bodies and an assortment of companies in sectors from manufacturing to medical engineering to information technology.

About 40% of the members represent private companies – among them the SMEs that make up a large majority of the European photonics sector. Of the roughly 5,000 companies that produce optical components and systems in the EU, fewer than 200 employ more than 250 people. These small and medium-sized enterprises form the very heart of our photonics industry and play an outsized role in driving innovation and economic growth. In cooperation with the European Commission, Photonics21 gives SMEs access to the latest technologies and provides prototyping services and pilot lines. It also gives them a network for partnering with large industrial players to market their innovations on a global scale.

Individual members and their organisations are located in almost every EU state and more than 50 non-EU countries. The five largest contingents are in Germany, Britain, France, Italy and Spain. At the core of Photonics21 are seven work groups that bundle member activities in cross-disciplinary, application-oriented fields. Through a combination of agenda-setting events, training programmes, workshops, publications and many other channels of communication, the platform has forged strong ties between research institutions, companies and policymakers across the EU and beyond. For SMEs especially, Photonics21 has become a platform to connect with researchers and expand their international and interdisciplinary networks.

Photonics21 has been a strong and supportive partner of the European Commission in the implementation of its innovation policies. In 2009, photonics was designated as one of six Key Enabling Technologies (KETs) in the European Research and Innovation Framework Programme (FP8) Horizon 2020. In 2013, the Commission established a Public Private Partnership (PPP) in photonics with the specific mission of accelerating innovation and time to market, fostering job growth and wealth creation, and mobilising additional private and public resources. To achieve these goals, the PPP financed 129 projects during FP7 (2007-2013) and has so far funded another 67 in the course of FP8 (2014-2020). These transnational projects cover the entire photonics value chain, from laboratory research to the testing and introduction of marketable products and services. To support the PPP, the European photonics industry, under the leadership of Photonics21, has pledged to spend four euros for every euro invested in the PPP by the Commission.

The pivotal role of photonics was recognised by the United Nations' declaration of 2015 as the "International Year of Light."

A promising outlook: fast-growing markets

Photonics is a highly dynamic and fiercely competitive global market that was worth EUR 447 billion in 2015. At a compound annual growth rate of 6.2% between 2011 and 2015, the global market has been growing substantially faster than the economy as a whole. A global market share of 15.5% makes Europe the world's second-biggest supplier of photonics, after China. With China currently focusing on photovoltaics, displays, lighting and other commodity products, however, Europe is arguably

the centre of global photonics innovation today. That said, China is pushing strategically into more innovative areas. European companies are market leaders in such sectors as production technology (including industrial lasers), optical components and systems, sensors and automated vision, as well as photonics in medicine and life sciences.

If Europe can stay at the forefront of photonics innovation and capitalise on fast-expanding global markets, a tripling of European production to more than EUR 200 billion by 2030 is realistic.

Today, Europe's photonics sector comprises some 5,000 companies producing optical components and systems. Most of them are highly specialised SMEs. The sector is export-oriented and research-intensive. It invests close to 10% of revenues in R&D, about twice the rate of manufacturing as a whole. The sector directly employs over 300,000 people. If one includes everyone whose livelihood depends on the use of photonics – from workers using industrial lasers to doctors performing endoscopic surgery – 10% of the workforce and as much as 30% of the entire economy already depend on photonics technology.

Fundamental innovation trends will continue to drive strong growth in photonics employment and revenues until 2030 and beyond. These trends include the development of optical computing to replace silicon circuits, as well as the spread of optical sensing and light-generating technologies in healthcare, mobility, industrial manufacturing, energy and many other sectors.

With its excellent starting position, the European photonics industry is poised to generate jobs and wealth in the future. Yet given the rapidly evolving and highly innovative nature of photonics technology, there is no guarantee that Europe will capitalise on its future opportunities.

Mission 2030: winning the future

To take Europe's photonics industry to 2030 and beyond, it will not be enough to focus solely on individual research projects. While EU support for these projects has been of outstanding value and should be continued, our future focus will be trained even more closely on creating the markets of tomorrow today. That means enabling the transfer of breakthroughs in photonics technology into successful products and services that create new jobs, resolving our most important societal challenges and improving the lives of European citizens.

Enabling breakthrough innovation. Photonics is the driver for many game-changing innovations that will define Europe's ability to bring disruptive new technologies to market. The switch from electronics to photonics in computing and other information technology is one such major technological shift. Micro-level medical imaging that takes diagnosis and treatment down to the cellular level is another. While Europe is at the forefront of basic research areas such as these, it will take a massive, collective effort to turn breakthrough innovations into market-ready products. This report outlines a number of potentially disruptive missions and the steps that could help realise them.

Responding to societal challenges and improving people's lives. As a transformative technology, photonics is at the centre of our efforts to rise to the major challenges faced by our societies in the 21st century. Demographic ageing will place even greater emphasis on technologies that diagnose diseases earlier, treat them faster and do both at lower cost. A growing, more informed population will demand safe, nutritious and affordable food. Sustainable resource use and the decarbonisation of the economy will require huge technological leaps in energy generation, the reuse of resources, connected mobility and smarter living in an urbanised world. Pervasive digitisation will put a premium on fast communications, powerful computing and Industry 4.0 technologies. The solutions to all of these challenges will be enabled by photonics, as we demonstrate on the following pages.

Leveraging European innovation for greater economic impact. To ensure that the European photonics industry continues to outperform the rest of the manufacturing sector in driving growth and creating employment, several obstacles need to be overcome. While the industry has invested more than four euros in R&D for every euro of support from the European Commission, more can be done to leverage other sources of funding and investment, including national R&D budgets and private venture capital. Entrepreneurship opportunities in the sector abound, but less than 2% of European venture capital investment goes to

the photonics sector. We must continue to engage with public and private early-stage investors and tear down other barriers to entrepreneurship in the sector. Finally, as a technology that straddles multiple scientific disciplines and industrial sectors, photonics depends on collaborative projects and networks to realise its full technological and market potential.

About this report

The remainder of this report is divided into eight sections. Each section begins by outlining one of the major challenges facing Europe and the world today. It then presents a vision of how photonics technologies that are already in the innovation pipeline can help us solve these challenges by 2030 and beyond. Given the tremendous breadth and diversity of photonics technology and potential applications, the report lays absolutely no claim to completeness. Nor does it seek to inventory "where photonics is at today" or will likely be in five years. Instead, it zooms in on where we strongly believe the industry is heading.

Each section is prefaced by a succinct mission statement. A broader scenario for 2030 is then portrayed, supported by evidence for the disruptive potential of photonics technology in each market. For readers who wish to dig a little deeper, we also present a pioneering solution that makes the case for how photonics will alter our approach to crucial challenges. A glimpse at a few other emerging technologies rounds out the picture of photonics innovations already in the pipeline. Each section then concludes with a brief discussion of the obstacles that must still be overcome before our vision can be realised.

The closing section of this report maps out the way forward with a 12-point agenda for policymakers.

Joint development of core photonics technologies – the key to successfully exploiting potential in industry

Photonics is the technology of light. Recognising its tremendous impact on the European economy and society at large, the European Commission has singled out photonics as one of six Key Enabling Technologies (KETs) for Europe. Four examples illustrate the breadth and versatility of photonics applications:

Infrared spectroscopy is a technique widely used in both research and industry. In the food industry it is used for quality control. It can also detect leaks during the transportation of natural gas. It is a crucial element in process engineering – in polymer production, for example, and in the fabrication of semiconductor microelectronics. Further applications range from forensics to the preservation of cultural heritage.

Light detection and ranging (LiDAR) is these days touted as one of the key enablers of self-driving cars. Yet it also opens up completely new applications in precision farming, in the conservation of biological diversity, in remote sensing and meteorology, in the gaming industry, in robotics and autonomous logistics, and in the optimisation of both wind and solar power generation.

Optical fibres are basic optical components that come in many different forms. One of these is the basis for the fibre-optic data transmission that already is at the heart of modern communication, and will become even more critical going forward. Optical fibres are also fitted in numerous sensors and used for power transmission. In medicine, they serve as light guides and for imaging, while their use in endoscopes also facilitates minimally invasive surgery.

Laser diodes are widely used in barcode readers and laser printers. They are also common in laser pointers and range finders. However, high-power laser diodes likewise deliver leading-edge performance gains to industrial applications such as cutting, drilling and welding. Medical applications, too, include various forms of laser diagnostics and laser surgery. Laser diodes are key components in the 3D scanners that open the door to virtual reality, mixed reality and holography applications. Many of the most advanced 3D printers today use laser diodes to manufacture individualised, next-generation products.

This very limited and incomplete list alone gives a telling insight into the seemingly endless possibilities open to photonics. However, to fully exploit the enormous potential of light in terms of new products and markets, it is vital to ensure that core technology development is carefully aligned and well-coordinated. New ideas for photonics applications often spill over from one very specific area of the photonics community, or even from basic photonics research. It then takes interaction within the photonics community to test the initial idea and transfer it to new areas. In this way, new, innovative products for markets as diverse as medical, automotive, gaming and process engineering can be spawned by a single idea or development in one or other of these areas – or even a totally different one. Precisely because this is so, the entire value chain – from basic research to component development and systems integration – must be framed within a joined-up overall strategy that engages the smartest minds in Europe.

Clearly, the next wave of photonics innovations is most likely to arise from emerging fields such as integrated photonics, micro and nanophotonics, silicon photonics, plasmonics, metamaterials, quantum optics and – perhaps most importantly – new concepts like digital photonics, which also spans 3D sensors and computational imaging. A holistic approach is thus needed to keep the photonics pipeline well filled and keep Europe competitive in these newly emerging technologies and markets. It is imperative for Europe to maintain this overarching strategic approach towards technology development if the ambitious missions staked out by the European Photonics community – and discussed in the subsequent sections of this document – are to be realised.

Live longer, feel better
Photonics in life sciences and healthcare

Our mission:
instant diagnosis of major diseases

"Already, photonics plays a crucial role in the diagnosis or treatment of virtually every major disease."

© chombosan / Fotolia

In 2030, healthcare will be fast, precise and cost-effective. Advanced diagnostics, pervasive monitoring and innovative e-health applications will be able to detect body signals, symptoms and diseases early on. Treatment will be highly targeted, minimally invasive and increasingly effective, reducing disability and mortality from cancer, strokes and other major diseases. Diagnosis and treatment will be delivered instantly at the point of care, thanks to the new science of "theranostics." With the help of these and other innovations, Europe will keep an ageing population healthy and fit.

Market outlook and potential for disruption

The figures speak for themselves: Over 30 million people worldwide die each year from the top ten medical conditions, which include heart disease, lung cancer, strokes and chronic obstructive pulmonary disease (COPD).[1] Richer diets and sedentary lifestyles have gone hand in hand with the spread of obesity and other health risk factors, contributing to 10 million early deaths from type-II diabetes and other nutrition-related causes.

In Europe, these challenges are compounded by rapid population ageing: The number of EU citizens aged 65 and older is expected to double by 2030. This will create immense additional pressures in medical and nursing care, not least due to dramatic growth in age-related diseases like Alzheimer's, dementia, macular degeneration, kidney failure, osteoarthritis and cancer.

These shifts will have dramatic consequences for European citizens and their healthcare systems. Healthcare spending has already reached nearly 10% of the EU's GDP, or almost EUR 1.5 trillion[2] a year. In the years ahead, it is expected to grow much faster than the economy as a whole as Europe's population ages. New technologies and concepts are therefore needed not just to maintain health and treat disease, but to do so more effectively and at lower cost.

Photonics is a fundamental driver of innovation in technology, processes and business models in life sciences and healthcare. As such, it will enable us to meet these challenges head-on. Already, photonics plays a crucial role in the diagnosis or treatment of virtually every major disease – from optical diagnostics and endoscopy to minimally invasive surgery and medical lasers. These and other photonics-based procedures allow us to treat conditions that a decade or two ago would have gone untreated, or where treatment had only a slim chance of success. Because photonics technology underpins so many innovative and less invasive therapies (think laser micro-surgery), doctors can now treat even very old patients. Moreover, the cost-saving potential of photonics in preventive medicine, early-stage diagnosis and highly personalised treatments is only now beginning to be tapped.

European universities, research institutions, technology companies and healthcare providers form the core of a rich innovation landscape in medical photonics, one of the fastest-growing sectors in the worldwide photonics market today. As a result, Europe is already a global leader and excellently placed to corner a growing slice of the

market for healthcare photonics, which is expected to reach around EUR 50 billion worldwide by 2020[3] and continue to outpace general economic growth in future decades.

Pioneering solution: "theranostics" for faster, more efficient treatment

One of the most exciting areas of medical innovation is the fast-emerging sector of "theranostics" – precision medicine that combines diagnostics with therapy to treat diseases earlier and faster. This kind of treatment would already be unthinkable without photonics. For example, doctors can now combine endoscopic diagnostics with simultaneous treatment by applying minimally invasive surgery techniques, replacing the traditional process whereby laborious diagnostic procedures were separated from treatment, often by a considerable time lag and to the detriment of the patient.

"Research is fast advancing on new tools that use multimodal imaging to let surgeons identify cancerous tissues and individual cells with unprecedented precision."

Yet it is the next generation of photonics technology, already emerging from European research centres, that holds out even greater promise. The focus is on cancer treatment, where current medical practices are often ineffective, especially when tumours are interconnected with vital organs or become resistant to drugs and radiation. The goal of theranostics here is to take diagnosis and treatment down to the level of the cell – with tools that simultaneously detect and destroy only pathological tissue while leaving healthy cells intact. The benefits of more effective and efficient cancer treatment for both patients and the healthcare system are obvious.

One of the most promising avenues for this kind of cancer treatment involves next-generation imaging technology in combination with minimally invasive laser surgery. Currently, the "gold standard" of surgical tumour removal is both time-consuming and imprecise, as it often entails an overly aggressive removal of healthy tissue. In complex organs like the brain, the excision of any cancerous tissue has to be extremely precise if patients are to maintain their bodily functions and quality of life.

Research is fast advancing on new tools that use multimodal imaging (including fluorescence, molecular imaging and other photonics technologies) to let surgeons identify cancerous tissues and individual cells with unprecedented precision. This can then be combined with high-precision lasers to immediately remove the pathological cells as they are identified. This "smart laser scalpel" could even see deployment in future robotic surgery and be applied to other medical conditions beyond cancer. Combining diagnosis and treatment in a highly precise and effective tool will help patients live longer, healthier lives while substantially reducing the cost of treatment.

Innovation pipeline in healthcare photonics

Theranostics is only one emerging medical technology that makes novel use of light and optical sensing. Any number of other disruptive innovations in photonics will also redefine the way our societies provide healthcare:

- Mobile photonics devices for early and instant point-of-care diagnostics and treatment will increase speed, raise survival rates, reduce cost and improve efficiency.

- Advanced biosensors ("lab on a chip") will boost analytics and help control the spread of pandemics.
- Photonics-based diagnostics to monitor and assess treatment response will open the door to the practical implementation of personalised medicine.
- Photonics technology from other industrial sectors is seeing applications in healthcare as well. One innovation under development is the laser vibrometer for the detection of heart disease. Another is the 3D printing of implants such as synthetic bones.
- Robotics is being combined with photonics in assisted and automated minimally invasive surgery.
- Augmented-reality surgery visors superimpose data and x-ray images onto the surgeon's field of vision, raising the efficiency and precision of the surgery process.
- Innovations for the consumer market include the development of wearable devices – for example, photonic fibres woven into smart clothing that measures the wearer's medical condition and wellness.
- One of the biggest game changers in the market will be the use of "big data" analytics to speed up medical findings and clinical research, as well as administrative processes and services innovations. This shift will be enabled by a combination of ubiquitous sensor technology and high-speed fibre optics.

The way forward

To realise the full potential of photonics technology in the European healthcare market by 2030, the next phase of innovation support must focus not only on the scientific challenges, but on making sure Europe's technological lead continues to translate into competitive products, services and business models. Three aspects in particular are of huge importance:

Open up heavily regulated healthcare markets to new technology. Most of Europe's healthcare systems are not sufficiently conducive to new, disruptive technologies – especially not on the scale that photonics offers now and in the coming decades.

Review data protection rules to remove barriers to innovation while continuing to protect the privacy of European citizens. A sharper focus on the generation and utilisation of "big data" in cooperation with healthcare providers, clinics and new digital platforms will speed up innovation, verification and testing. It will also prevent the continued exodus of research activities to the United States and other jurisdictions that facilitate "big data" research.

Improve access to healthcare markets for innovative SMEs. Because most organisations and providers do not regard them as relevant market players, healthcare and life science start-ups and SMEs often have a hard time competing with incumbents.

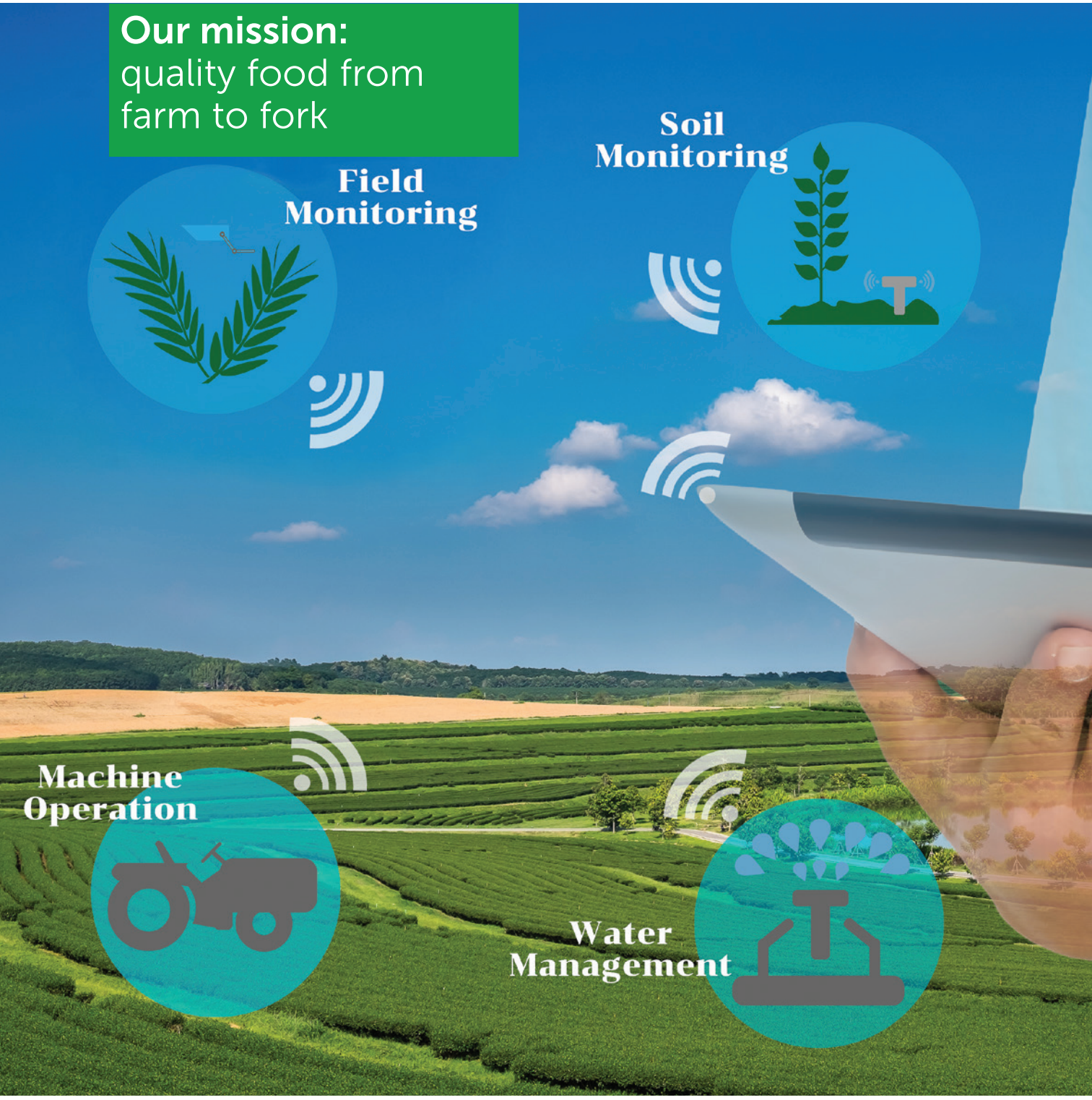
[1] www.who.int/mediacentre/factsheets/fs310/en/

[2] https://ec.europa.eu/health/sites/health/files/state/docs/health_glance_2016_rep_en.pdf

[3] www.photonics21.org/download/Brochures/Internet_Charts-_Photonics21_Market-Research-Report_v4.pdf

Feed the world

Photonics for safe, nutritious and affordable food



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In 2030, we will have the technology to feed the world, push back food-borne illness, and reduce the environmental footprint of agriculture, fisheries and aquaculture. Photonics will help supply safe, nutritious and affordable food for all and establish a sustainable value chain from farm to fork. By using ever more precise sensors and measuring devices, farmers, food processors and ordinary consumers will be able to monitor and certify the safety, quality, content and even the origin of food – anytime and anywhere.

Market outlook and potential for disruption

Feeding a global population projected to reach 10 billion by 2050 will require dramatic increases in food production. With agriculture already responsible for 70% of the planet's water use[4], 24% of greenhouse gas emissions[5] and environmental degradation on a planetary scale, boosting food production using current practices is clearly unsustainable.

At the same time, consumers are placing much greater emphasis on food safety, quality and value chain transparency. Growing concern is also focused on food waste: One third of all food produced is wasted during production, processing, distribution or at the point of consumption.

Photonics technology is a powerful toolbox for solving these challenges. Agriphotonics is already a fast-growing discipline in precision farming and environmental management. Relevant tools include lasers and LiDAR (light detection and ranging), hyperspectral imaging and many other kinds of sensors, as well as energy-efficient LEDs. These technologies can monitor soil health and hydrology, predict protein levels in grain harvests, determine when to pick fruit, map water quality to check the health of fish stocks, and screen for contaminants in produce. Food processing, too, is becoming safer, more efficient and less wasteful thanks to photonics technologies such as optical sensors, imaging and labelling. At the point of sale and consumption, the wider use of scanning and spectrometry will enable food content, spoilage and/or potential toxins to be identified with far greater accuracy.

Europe is the world's largest exporter of agricultural and food products, with the sector responsible for 7% of all jobs and 6% of European GDP[6]. From precision farming to food processing, Europe is the technology leader and will therefore play a central role in meeting these challenges. In particular, Europe is in the vanguard of high-tech precision farming, where photonics is central to a major technological shift in the way farmers grow food. The global market for precision farming equipment and services is expected to grow from USD 3.3 billion in 2016 to USD 5.9 billion in 2021, an annual growth rate of 12.4%.[7]

Pioneering solution: safe and transparent food production

In a future of efficient high-tech farming, aquaculture and food processing, photonics will play an increasingly important role in raising

supply, lowering resource use, curbing environmental degradation and reducing waste all along the value chain. As we fight to push back food-borne disease and contamination – and as consumers become increasingly concerned about the provenance, quality and safety of their food – photonics will also be crucial in establishing a no-gaps system that securely monitors the entire value chain from farm to fork and certifies the origin and content of what is served on our tables. On the farm, increasingly sensitive imaging will be able to detect the earliest onset of fungus, mildew, pests and disease, vastly reducing the need for agricultural chemicals. Spectrometry and laser scanning will detect produce ripeness and determine the perfect time to harvest and ship. In food processing, hyperspectral imaging combined with intelligent software will make it possible to identify and remove defects and foreign matter that traditional cameras and laser sorters miss. At the same time, fluorescence spectroscopy can monitor amino acids, vitamins, allergens and other components in foods.

"Spectrometry and laser scanning will detect produce ripeness and determine the perfect time to harvest and ship."

At the retailer level, and especially at the consumer level, spectrometers connected via smartphones have already appeared on the market but are still limited in their functionality. When the next generation of sensors arrives, retailers and consumers will be able to pinpoint the likely origin of produce based on a unique "fingerprint" of parameters such as sugars, phenols, amino acids and anti-oxidants – without taking a sample or even breaking the package. Photonics will thus protect the high quality of European food production, increase trust between producers and consumers, and empower citizens to make better food and nutrition choices. It will also mark a significant step forward in protecting the European Union's Guarantee of Origin system against cheap substitutes and counterfeit products.

Innovation pipeline in photonics for agriculture and food

Food and farming, including hydroponics and aquaculture, are a vast and complex area where photonics technology has already seen widespread deployment at many links in the value chain. Here are just a handful of examples of new fields where the development of agriphotonics will yield major benefits:

- As technology improves and knowledge grows, and as consumers demand shorter farm-to-table distances, indoor and urban farming in warehouses or underground spaces is becoming increasingly attractive economically. Vertical farms will grow produce on multiple levels, conserving space and especially water in comparison with conventional greenhouses. More carefully controlled environments will also improve the taste of produce. New lighting and sensing technology will be indispensable in turning this vision into reality.
- Research into specialised LEDs and lighting algorithms will optimise growth and yield in greenhouse and indoor environments. Ultraviolet LEDs can combine light with effective control of plant disease such as fungus and mildew.

- Photonic sensing has a crucial role to play in fish, shellfish and algae farming as the sector increasingly shifts towards more complex land-based and indoor systems in order to minimise the often destructive environmental footprint of traditional aquaculture. Photonics monitors water quality, oxygen and salt content, pests and diseases, and the quality of the product.
- The development and widespread deployment of sensor technology will allow individualised "sell-by" dates that replace the hypothetical risk of spoilage with the actual risk. This will eliminate a significant source of food waste at the retail and consumer level.
- Another challenge for agriphotonics is monitoring soil health, including compaction and the concentration of organic matter, nutrients and chemical residues, as well as hydrology. Techniques to measure soil health include 3D lasers and various types of photonic sensors.

The way forward

The agriculture and food sectors have some unique characteristics that raise barriers to investment and slow down the adoption of new technology. Three policy responses would help ensure that agriphotonics can fulfil its potential:

Spread technology via agricultural extension systems. Low margins and fluctuating food prices limit farmers' willingness to invest in new technology. Many players along the entire food value chain tend to rely on traditional know-how instead of state-of-the-art precision methods. In order to help farmers understand and access new technology, and to assist them with investment decisions, policymakers and industry associations should leverage existing agricultural extension systems and, where necessary, build them out.

Strike a smart balance with regulations and standards. Regulations protect consumers and ensure the safety of food. But regulations can also hinder the introduction of new processing technology and farming techniques. This balance has not always been properly achieved in the past. Member state governments and the Commission must be very careful to find the right balance.

Support technology uptake by smaller farms. Unlike other agricultural superpowers such as the United States, Canada and Brazil, Europe still has a large and vibrant sector of small farms and food processors – not only as a legacy of the past, but also due to increasing demand for regional, organic and specialty produce. Solutions include technology-focused support for cooperative associations and the leasing or sharing of equipment by farms and processors. This will require a special approach by the industry, and specific policy support would help make investments viable in smaller niche markets.

[4] http://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture
[5] www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data#Sector
[6] European Commission, "The EU's common agricultural policy (CAP): For our food, for our countryside, for our environment", EU publication, 2014
[7] www.bccresearch.com/market-research/instrumentation-and-sensors/precision-farming-markets-report-ias111a.html

Keep our traffic flowing
Photonics for connected mobility

Our mission:
accident and congestion-free road transport

"Photonics technology holds many of the keys for making vastly safer, more efficient and more comfortable mobility services a reality."

© chombosan / Fotolia

In 2030, our mobility will be based on multimodal transport. Driving will be automated, connected and electric to maximise safety, efficiency and comfort. Photonics provides essential components, systems and production tools for all aspects of connected mobility, from driver assistance and traffic monitoring to photonics-based IT and telecommunications.

Market outlook and disruption potential

Mobility is fundamental to our modern world. In its present forms, however, it comes at an unsustainable cost to society in terms of pollution and energy use, urban congestion and wasted commuting time, not to mention death and disability from accidents. Transportation accounts for 23% of Europe's greenhouse gas emissions.[8] Commuters spend 70 minutes travelling from home to work and back again each day in Brussels and Cologne, and over 100 minutes in London.[9] Europe could gain EUR 1 trillion in GDP each year simply by switching 30 minutes of lost commuting time per day to productive work time.[10] Over 25,000 Europeans die in road accidents each year.[11] Most of these accidents could be avoided – or their consequences greatly mitigated – by means of automated driving, by implementing the European Commission's directive on Intelligent Transport Systems (ITS) and by following the European eCall initiative for automated roadside assistance. Increasing urbanisation, the explosive growth of logistics and delivery services and the needs of an actively ageing society put additional pressure on mobility systems.

Photonics has been an aspect of transportation from its earliest days (think lighting and signals). Now, photonics technology holds many of the keys to make vastly safer, more efficient and more comfortable mobility services a reality. Automated driving enabled by sensors, imaging and wireless connectivity will boost safety, free up road space and enable traffic flows to be optimised in real time. Novel display and augmented reality technologies will assist drivers and create new interior environments in private and public transportation, while the next generation of photonics-based IT and telecommunications will facilitate the high-performance, zero-downtime connectivity needed to make connected mobility safe and reliable. On the production side, new laser-based manufacturing technologies will help the industry build lightweight vehicles that use less energy and cost less to produce without compromising on crash safety.

In the EU, private households alone spend over EUR 1 trillion a year on transportation – including cars and fuel, air and rail travel, taxis and public transport. Although Europeans remain concerned that future value creation in a connected, data-rich transportation industry could shift to global internet-services companies, Europe has every reason to stay confident about its prospects in this sector. The European photonics industry is a global leader in automated vision, sensors and imaging, the core technologies at the centre of the mobility revolution. A rich network of technology companies supplying Europe's highly innovative auto, truck, train and aircraft producers, coupled with

world-class public transportation systems and a sophisticated logistics sector, gives Europe a powerful starting position in the fight for tomorrow's mobility market.

Pioneering solution: LiDAR as the "eyes" for safe automated driving

In the race to put safe self-driving vehicles on the road, photonics technology is essential. Without intelligent automated vision using cameras, lasers, radar, sensors and other optical devices, cars cannot drive autonomously – especially since GPS-based navigation will remain unreliable in the medium term due to the bottleneck in telecommunications coverage and connectivity.

"New technology can detect stop signs, pedestrians and lampposts through twilight, darkness, dust, fog, rain and other adverse weather conditions."

The most promising technology for automatic driving is LiDAR, which stands for light detection and ranging. The laser-based method is not new: It was first developed during the Apollo space programme to let astronauts map the surface of the moon. But only now are companies developing ways for the systems to work with enough precision to generate the high-resolution 3D vision that is necessary for safe automated driving. New developments include a 3D flash LiDAR that overcomes a laser's usual limitation of needing a very clear field of vision. The new technology can detect stop signs, pedestrians and lampposts through twilight, darkness, dust, fog, rain and other adverse weather conditions. When combined with high-resolution cameras and conventional radar, LiDAR technology will make automated driving safe.

European makers of cars and trucks, together with their network of suppliers in the photonics industry – including many start-ups and SMEs – are making rapid strides forward in LiDAR and other automated driving equipment, as well as in the software algorithms that enable intelligent machine vision. While it will be a number of years before fully self-driving cars are ready to roll, Europe still has excellent prospects of winning the race.

Innovation pipeline in photonics for connected mobility

Besides LiDAR, many other emerging photonics innovations will help make the vision of connected mobility a reality. A few examples:

- New photonics-based manufacturing technologies, like high-speed laser cutting and additive manufacturing, will save energy and material inputs and produce lightweight, fuel-efficient cars at lower cost.
- Traffic and parking space management is an integral part of efficient connected mobility, and will depend on new photonics products such as intelligently networked cameras and sensors.

- Street lights, traffic signals and other transportation-related lighting are a major consumer of electricity. New LED solutions will permit significant energy savings. This infrastructure can also be combined with other functions such as transmitters for automated driving.
- Improved sensing and imaging will do a better job of detecting pollution and environmental conditions (such as rain, sunlight, exhaust gas, CO2 concentrations and particulates) and even measuring the quality of fuel.
- Robust new sensor technology to detect NOx and SOx will lead to significantly cleaner, more efficient combustion engines as the industry transitions to other technologies.
- Future vehicle interiors will feature innovative human-machine interfaces that involve gesture recognition, augmented reality and advanced infotainment solutions, all using OLED displays.

The way forward

Photonics-based technologies will enable a new era in safe and connected mobility services and equipment. To make sure Europe can leverage its strong industrial and technological position, policymakers must take several actions at the European and national levels:

Create a comprehensive European framework for testing that addresses the liability issues and ethical questions that relate to fully automated driving. The European Commission has a crucial role to play in bringing together national regulators, transportation operators and the corporate sector – including the insurance industry – to create a borderless framework and make sure that next-generation mobility becomes an integral part of the Single Market.

Address data ownership and privacy issues to build a well-functioning and interconnected system that preserves consumer trust and ensures that Europe's mobility industry can compete with global digital service companies. This should take place at the European level to create a level playing field, both among the member states and vis-à-vis non-European competitors.

Support a common approach to regulation and infrastructure, including stricter urban emissions standards, better intermodal connectivity and a transnational charging infrastructure for electric vehicles. To fully realise the vision of connected mobility, Europe's many high-quality transportation systems must become even more interoperable than they are today, especially across national and regional borders.

[8] http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics

[9] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Top_20_most_congested_functional_urban_areas_in_selected_EU_Member_States,_2015_(%C2%B9)_(hours)_Cities16.png

[10] Estimate based on Eurostat data

[11] https://ec.europa.eu/transport/road_safety/specialist/statistics_en

Zero emission, less waste

Photonics for sustainability and a clean environment

Our mission:
a truly circular economy

"The use of intelligently networked pollution detectors will give us unprecedented control over air and water quality."

© Romolo Tavani / Fotolia

In 2030, Europe's economy will be cleaner, greener and far along its path towards decarbonisation. Photonics technology will help put an end to the depletion of resources by managing material streams in a circular economy, reducing energy consumption in buildings and public spaces, creating efficient industrial processes, developing the next generation of photovoltaics, enabling smart mobility and monitoring our environment in real time.

Market outlook and disruption potential

Between now and 2030, the European Commission and the member states have committed to an ambitious agenda to ensure the long-term sustainability of our way of life. Items on the agenda include a 40% reduction in greenhouse gas emissions compared to 1990 levels, a 27% share of renewable energy and a 27% reduction in total energy use compared with the business-as-usual scenario. Just as importantly, a healthy environment with clean air, clean water and clean food remains a basic right for all Europeans.

Green photonics is a powerful, indispensable toolkit for mastering all these challenges. As described elsewhere in this report, a new generation of laser-based production systems will bring forth new manufacturing processes that boast extraordinary energy and resource efficiency (see the section on manufacturing and production). In lighting, which consumes 20% of all electricity used, photonics will accelerate the transition towards low-energy LED and OLED lighting systems (see the section on smart homes and cities). Sustainable agriculture will receive a big boost from powerful new imaging and sensor technology (see the section on agriculture and food). The use of intelligently connected pollution detectors will give us unprecedented control over air and water quality. And the next generation of photovoltaics systems, including those made from organic polymers, will greatly accelerate Europe's shift from fossil fuels to renewable energy.

Green photonics – technologies that generate or conserve energy, produce light or reduce emissions or pollution – is already one of the largest and most important sectors of the industry. With the exception of conventional photovoltaics, which has become a commodity industry based mainly in Asia, the European photonics industry is excellently placed to help achieve some of our most important societal goals while creating new jobs and driving growth in the sector.

Another fast-growing market segment is remanufacturing: the refurbishment and reuse of products and components as a way to save material inputs and the energy it takes to produce them. Currently generating EUR 30 billion a year and employing 190,000 people, the sector could triple its turnover by 2030 and give work to nearly 600,000 people in Europe.[12]

Pioneering solution: restructuring material streams

The smartest way to save resources is not to use them at all. To this end, huge sustainability gains will come from new photonics technologies – such as laser-based additive manufacturing – that use fewer material inputs.

Another imperative in reaching Europe's ambitious sustainability goals is to create a truly circular economy that recovers as many resources as possible. The European Parliament has set a target that envisages 70% of municipal waste being recycled by 2030, compared to 44% in 2014.[13]

To achieve this goal, products will increasingly be designed with reuse in mind, especially of components and scarce materials that cannot be effectively recovered using conventional recycling methods. This "circular economy design" approach – already under development for smartphones and other consumer IT equipment – is built on principles made possible by photonics technology: longer lifetimes for parts and components thanks to high-precision, zero-defect production; high-speed disassembly; and automated sorting through the advanced optical recognition of reusable parts and materials. Together, these technologies will significantly improve end-of-life management and create a more sustainable value chain.

"Laser-based disassembly lines will be able to separate complex products into components for further use."

The remaining technological obstacles to higher resource recovery rates are significant but no longer insurmountable. To solve hitherto impossible sorting challenges, European companies are developing systems that use multispectral and hyperspectral imaging to separate industrial and household waste. Laser-induced plasma spectroscopy is another technology that can precisely identify materials – such as different types of metal alloys and plastics – that previous generations of sensors could not. Another emerging technology, the fluorescent tagging of objects during production, will allow sorters to identify them at the moment of disposal. Laser-based disassembly lines will be able to separate complex products into components for further use. Combined with increasingly sophisticated software algorithms and advances in artificial intelligence, these photonics technologies will power a new era of sustainability and enable Europe to operate a virtually circular economy by 2030.

Innovation pipeline in green photonics

The circular economy is, of course, only one aspect of the sustainable economy and society that photonics technology will help us achieve. In addition to the many efficiency-boosting technologies described elsewhere in this report, future contributions of green photonics to Europe's sustainability goals also include the following:

- Development of the next generation of solar power – organic photovoltaic (OPV) devices – is proceeding rapidly. OPV devices are cheaper to produce, and can easily be applied to virtually any surface. Even indoor photovoltaics (to recapture the energy of artificial lighting) may become feasible. These advantages are so profound that OPV devices could replace conventional photovoltaics for many applications, giving European companies an opportunity to win back market share from Asian producers.

- A new generation of intelligently networked optical pollution sensors will improve the real-time detection of toxic substances. Ultraviolet LEDs and other photonics technologies play an increasingly important role in purifying air, water and food.
- In addition to the efficiency gains from additive manufacturing discussed in the next chapter, another emerging benefit is the possibility of designing entire products from a single material, greatly boosting both production efficiency and ease of recycling after disposal.
- Photonics technology is also indispensable for e-mobility. Lightweight cars, batteries and fuel cells all require laser tools for their production. These products, too, will become greener as laser-based manufacturing reduces downtime, defects, attrition, chemical waste and energy consumption.
- Fibre optics shrinks the carbon footprint of the internet. Data centres already produce as many greenhouse gas emissions as all the world's air travel.[14] Greening the global IT infrastructure is therefore an imperative in our fight to reduce emissions.
- Adaptive lighting systems that use sensors to automatically switch off lights in buildings and on streets will significantly reduce energy consumption and light pollution.
- Revolutionary technologies like artificial photosynthesis and solar fuels could one day pave the way to a green age of energy independence where we have the ability to store and use solar power on demand.

The way forward

To meet sustainability goals more reliably than in the past, Europe must make better use of the potential of green photonics to reduce energy and resource use. At least three steps must be taken in this direction:

Focus emissions abatement on the sectors that contribute most at the least net cost. While many current decarbonisation policies in Europe come at an increasingly unsustainable cost to citizens and society, both the transition to efficient lighting and waste recycling yield large-scale reductions in emissions at substantial net financial benefits.[15]

Revamp current emissions abatement schemes such as feed-in-tariffs to encourage openness to new technologies. This should include organic photovoltaics and solar fuels, and should provide a clear mechanism to support efficiency gains.

Adjust the regulatory framework to achieve the circular economy, providing the push and incentive for industry to move forward. Current certification regimes should be ramped up to make product sustainability transparent to all end users. The binding expansion of recycling rates, pay-as-you-throw schemes, producer mandates and possible public support should also be considered.

[12] www.remanufacturing.eu/wp-content/uploads/2016/01/study.pdf
[13] www.europarl.europa.eu/news/en/press-room/20170123IPR59605/waste-boost-recycling-cut-landfilling-and-curb-food-waste-say-meps
[14] www.theguardian.com/environment/2015/sep/25/server-data-centre-emissions-air-travel-web-google-facebook-greenhouse-gas
[15] www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/pathways-to-a-low-carbon-economy

Empowering Industry 4.0
Photonics in manufacturing and production

Our mission:
a million
new jobs

"Manufacturing is already undergoing a photonics revolution, with earlier generations of factory machinery increasingly giving way to lasers and sensors, usually in conjunction with robots."

© ABB

In 2030, European factories will be fast, green and flexible. Photonics technology, including lasers, sensors and 3D displays, will revolutionise industrial production and working environments, making manufacturing more innovative, cost-competitive and resource-efficient. A fully digital value chain from supplier to customer will birth new forms of collaboration and customisation, new services, and new business models – all of which will strengthen Europe's industrial base.

Market outlook and disruption potential

Europe's singularly diverse manufacturing companies provide over 20% of all jobs directly, plus at least as many indirect jobs among firms that offer services to these companies or sell their products. Responsible for two thirds of all private R&D, Europe's industrial sector is also a driver of innovation and will play a central role in solving the societal and technological challenges of tomorrow. To secure jobs and create wealth for our societies, a thriving, sustainable industrial sector remains essential.

That said, Europe's industrial companies, large and small, face some daunting obstacles ahead. Accelerating technological change – from the disruptive digital business models emerging from Silicon Valley to the marriage of robotics and artificial intelligence on the factory floor – has put Europe's manufacturing companies under relentless pressure to adapt or lose out to nimbler competitors. Chinese and other emerging-market companies are rapidly climbing the innovation ladder, creating even tougher competition in the future. The sector must become even more efficient in its use of energy and other resources.

Photonics is a vital enabling technology for sustaining European industrial competitiveness, powering product innovation and creating a greener economy. Manufacturing is already undergoing a photonics revolution, with earlier generations of factory machinery increasingly giving way to lasers and sensors, usually in conjunction with robots. Because these technologies have been digital from the start, they are also at the heart of the manufacturing sector's strategies for "Industry 4.0" – a fully digitised and connected value chain from supplier to customer that will enable a new era of high-precision, cost-competitive and resource-efficient production, fast and flexible mass customisation and new services built around manufactured products.

Europe is particularly well placed to meet these challenges. Its strength in industrial photonics is part of its overall leadership in industrial technology, including machine tools and robotics. The global market for industrial laser systems – the largest manufacturing category for photonics – was worth EUR 11.4 billion in 2016, up 7.4% from the previous year. European photonics companies control about one third of this market.

Importantly, photonics plays a dual role in the industrial sector: as a fast-growing and highly innovative sector in manufacturing, and as an enabling technology to help all other sectors of manufacturing compete successfully with their global rivals.

Pioneering solution: laser-based additive manufacturing

Photonics is the key enabling technology to make the European factory of the future smarter, greener, safer, more digital and more flexible. In manufacturing, high-precision lasers are fast replacing the machinery conventionally used to cut, weld, solder, drill and structure metals, plastics and composites.

These laser systems are much more than just versatile manufacturing tools. They are at the heart of creating a fully digital and connected value chain. Because lasers – in combination with new digital design tools like 3D visualisation – can immediately convert any data into a physical part, they will allow manufacturing companies to shift from mass-producing identical products to mass-producing completely individualised products. Given such flexibility, laser systems are also slashing the product lifecycle by eliminating the need for new machinery or set-up time. Quality control, which used to be a separate process, will be integrated into production, because lasers and their sensors "see" deviations in real time, thereby reducing defects and downtime.

"Technology will pave the way to new business models, such as on-demand manufacturing, that will give Europe the opportunity to boost its competitive advantage and strengthen its industrial base."

What's more, lasers are key enablers for the fast-emerging technology of additive manufacturing (also known as 3D printing) that will revolutionise industrial production over the coming decades. Additive manufacturing based on a new generation of laser systems allows the creation of complex shapes, lightweight constructions and miniaturised parts down to the micro and nano scale that were impossible to build with conventional machine tools. Unprecedented precision, speed and flexibility will give birth to new, innovative products and vastly reduce resource use across the entire industrial sector.

The greatest potential for laser-based additive manufacturing to trigger disruption stems from a simple fact: It eliminates the need for large factories with a huge variety of machines, each responsible for a discrete production step. By allowing flexible, on-demand manufacturing, this technology will accelerate the shift to "re-shore" production to Europe. Companies will seek to be closer to their customers, speed up the product cycle, and reduce the complexity of their global logistics – even as the Internet of Things (IoT) lets them integrate production ever more deeply into supply chains, workflows and after-sale service.

Additive manufacturing technologies will revolutionise production processes in other ways as well. Rapid prototyping will become ubiquitous and mass customisation ("lot sizes of one") a reality. That goes for one-off products such as spare parts, but also for any customised and complex product – including the point-of-use production of individualised medical implants or connecting parts. By simplifying the supply chain and reducing required inputs, additive manufacturing will significantly cut the carbon footprint of industrial production. Lastly, the technology will pave the way to new business models, such as on-demand manufacturing, that will give Europe the opportunity to boost its competitive advantage and strengthen its industrial base.

Innovation pipeline in industrial photonics

Because of their central role in transforming production, high-performance lasers and other photonics components, systems and processes are the most promising innovations in manufacturing. A few of the emerging technologies are listed below:

- High-power lasers have revolutionised industrial processing, introducing precision manufacturing technology even for small lot sizes. The next generation of laser systems (like ultra-short pulse lasers) is geared towards higher throughput and flexibility for faster and more efficient production.
- Extreme ultraviolet (EUV) lithography systems are a new technology for generating nano-sized structures, opening the door to a new era in the manufacture of smaller and faster microprocessors, including optoelectronic and photonic integrated circuits.
- Fibre optics will be the backbone and neural system of the Industrial Internet. Connected and interlocked production systems call for end-to-end optical switching with high bandwidth and low latency. Only a "fibre to the premises" infrastructure will be able to deliver the quality of service needed for Industry 4.0 applications.
- Advanced optical sensors, 3D machine vision and 3D imaging are laying the foundation for high-precision, interruption-free production processes and autonomous robots.
- Predictive maintenance enabled by optical sensing, surveillance systems and non-destructive testing technologies such as infrared will reduce equipment breakdowns. That in turn will help eliminate cost-intensive downtime in production facilities.
- Optical computing will drive artificial intelligence and smart robotics, as deep learning requires an enormous amount of computing power in the smallest possible spaces.
- The industrial production of micro and nanomaterials and structures is another rapidly evolving spin-off of high-performance lasers. These production technologies are a fundamental prerequisite to get many nanotechnology applications out of the lab and into the market.
- Rich visual communications such as augmented reality and 3D display technology are transforming every aspect of the manufacturing process, from product design to production to maintenance.

The way forward

The implementation of an Industrial Internet built around customised products, connectivity along the entire value chain and photonics-enabled production technologies such as additive manufacturing will radically transform European manufacturing. The industry, however, is dependent on policy support in several key areas:

Strengthen the European ecosystem of SMEs, start-ups and research institutes in laser-based production technology. Better ecosystem infrastructure is needed to deliver a steady stream of education, expertise and innovation in a growing market.

[16] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Relative_fig2_importance_of_Manufacturing_(NACE_Section_C),_2014.png
[17] www.optech-consulting.com/html/pressemitteilung_15__maerz_2017.html

Support a powerful and secure telecommunications infrastructure that fully meets the requirements of the Industrial Internet. Machine-to-machine communication in a fully digital industrial value chain has much more exacting demands in terms of speed, reliability, latency and security. Pervasive connectivity makes every industrial company vulnerable to various forms of illegal access, including industrial espionage and sabotage by state actors. The European Commission, member state governments and the private sector must urgently step up efforts to secure Europe's digital infrastructure. SMEs, in particular, often do not invest sufficient resources in cybersecurity.

Boost education and training. The transition to laser-based (additive) manufacturing, digital value chains and other technologies that underpin Industry 4.0 will require many new kinds of specialists covering everything from product design to supervision. Replacing conventional machinery with fully automated systems will also require the retraining of workers affected by this transition.

Define a common European standard for the Industrial Internet to manage interfaces and ensure the interoperability of smart machines and production processes. This must be done at the European level in close collaboration with industry stakeholders.


Collaboration
Cyber Security
Smart
Factory
Data Velocity
Big Data
Connect
Analytics
Cloud

A new quality of urban life
Photonics for smart homes and liveable cities

Our mission:
10% higher productivity

"Smart homes and offices will be development hotspots for the Internet of Things (IoT), requiring sensors, cameras, displays and many kinds of optical IT."

© deagreez / Fotolia

By 2030, digital connectivity will create an entirely new quality of urban life. Photonics technology, including lighting, sensors and optical IT, will supply the infrastructure for smart homes and thriving cities, thereby enabling us to live and work in attractive, secure and productive environments tailored to our individual needs.

Market outlook and disruption potential

Rapid urbanisation is one of the 21st century's defining megatrends. For the first time in human history, more people live in urban than in rural areas. By 2030, there will be more than 40 megacities with at least 10 million inhabitants. And by 2050, the proportion of humanity living in cities will rise to two thirds.

That is good news for citizens, for companies and for the planet. Cities are efficient (think short distances and public transport). They concentrate jobs and opportunities, and they serve as centres of creativity, collaboration and innovation. Cities are also a laboratory for technological and business model change, from mobility services to new forms of working and living.

Digital connectivity enabled by photonics will create an entirely new quality of urban life. Smart homes and offices will become development hotspots for the Internet of Things (IoT), requiring sensors, cameras, displays and many kinds of optical IT. One of the most significant areas for innovation and market development is efficient and intelligent lighting – indoors and outdoors – for two reasons: First, scientists have greatly increased our understanding of the effects of lighting on well-being, from mood and health to productivity in homes, schools and offices. Second, indoor lighting alone consumes around 20% of all energy, making it a vital target for efficiency gains and emissions reductions.

European companies are particularly strong in lighting technology, where they account for about one fourth of global production. Largely driven by the shift to LEDs, lighting has also been the fastest-evolving segment of the global photonics market, growing by around 10% a year since 2005. Intelligent lighting with improved properties for health and productivity is thus a core technology that Europe can leverage to create jobs and wealth as we build the smart homes and liveable cities of tomorrow.

Pioneering solution: human-centric lighting for health and productivity

Solid-state lighting (SSL) has shifted the paradigm in lighting technology. Ongoing advances in LED technology are rapidly bringing down production costs and further boosting energy efficiency. Building intelligent networks that link lighting and sensors will usher in the next phase of large-scale efficiency and productivity gains by automatically managing light (and energy) consumption whenever and wherever only a specific amount of light is needed. Smarter lighting will allow office and factory floor space to be optimised, generating yet more efficiency gains.

The most fascinating new frontier in lighting research is the way in which light sources interact with human health, well-being and productivity – a field known as human-centric lighting (HCL). Biologically optimal lighting is known to enhance alertness, focus and productivity. It also improves health by regulating our biological rhythm and hormone production, and lowers our likelihood of developing mood and mental disorders as well as a host of diseases such as cancer, diabetes, heart disease, obesity and insomnia.

"The social benefits of human-centric lighting include more effective prevention and treatment of mood disorders, mental disease and any condition with a psychosomatic component."

The first phase of this research has focused on LEDs that allow indoor lighting to mimic natural light. The next step is "smart" lights that automatically shift the light spectrum to mimic a natural cycle – even as the shift remains invisible to the naked eye. Connected to sensors that monitor our needs, these technologies could also adjust the quality of light for a specific effect – to encourage alertness or calm, for example. Further research will have to find the best blend of light for each situation, such as supporting the health of shift workers without compromising alertness and safety.

Better lighting quality – using only technologies that exist today, not the future advances described above – has already been shown to increase worker productivity by up to 23% and to reduce factory accidents by 50%. Outside the workplace, the social benefits of HCL include more effective prevention and treatment of mood disorders, mental disease and any condition with a psychosomatic component, as well as better educational attainments – even by students affected by ADHD and other conditions known to respond to HCL. That is why CL could prove to be one of the most promising technologies in this report, with very substantial knock-on effects throughout the whole of the economy and society.

Innovation pipeline in photonics for smart homes and cities

The process of building smart homes and liveable urban environments is not limited to HCL, but involves a wide spectrum of novel applications in photonics. Europe's technology pipeline currently includes key technologies such as these:

- Intelligent light management that networks lighting with sensors and IoT connectivity has tremendous potential to raise the quality and energy efficiency of lighting, as well as to create new lighting-based services. Intelligent lighting leverages a strong European supply chain and market position not only in lighting, but also in related fields such as sensors, controls and building systems integration.
- New manufacturing technology will be able to mass-produce flexible and/or transparent organic LED (OLED) lighting for large surfaces. These light surfaces or displays can be fully integrated in buildings, ceilings, walls and windows, and even used as design elements.

- Smart, connected street lights, traffic signals and illuminated traffic signs will be able to adapt to lighting conditions or the volume of traffic. Street lights will also serve as sensors and transmitters for fully automated driving technology and other wireless communications.
- Interior and exterior lighting can be used for data transmission, such as Wi-Fi that uses LEDs (and is thus called Li-Fi). This will provide yet another avenue for universal connectivity.
- Public security will be improved by new technologies for the video surveillance of public spaces and critical infrastructure. Photonics will enrich images with other data such as polarisation, distances and spectral analysis.
- Access control, intrusion detection and pattern recognition systems that feature biometric techniques will improve the surveillance and protection of public and private high security areas.

The way forward

There are three main areas where policymakers must become active before this vision can be achieved:

Make the public sector a lead innovator and integrator in lighting management. As the slow breakthrough of LED lighting has shown, smart regulation and the creation of critical mass to generate scale effects can be essential to market success – even in cases where a new technology is clearly superior. Any public sector outlays for lighting would generate an extremely fast payback through energy savings.

The European Commission and member state governments must strengthen cyber-security as a vital prerequisite for keeping the fully connected homes, offices and urban infrastructure of the future safe and secure and to retain the trust of citizens and consumers.

Facilitate collaboration across industrial sectors by providing public sector support. Because technologies relating to smart cities and homes involve many different consumer products, developing cost-effective mass production techniques and bringing down unit costs is especially important in this area if Europe's photonics industry is to enjoy continuing success.

[18] www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html
[19] https://blog.lsgc.com/wp-content/uploads/2016/04/Lighting-the-Way-to-Health-and-Productivity-White-Paper.pdf
[20] www.ecodesignconsultants.co.uk/healthy-buildings
[21] https://blog.lsgc.com/wp-content/uploads/2016/04/Lighting-the-Way-to-Health-and-Productivity-White-Paper.pdf

Building our digital society

Photonics for a secure and resilient IT infrastructure

Our mission:
zero downtime in a terabit economy

"Since light can travel vast distances through fibres, fibre optics consumes only a fraction of the energy used by conventional technology that transports electrons via copper wires."

© pressmaster / Fotolia

In 2030, our societies and economies will be fully digital. To make our digital society work and to safeguard trust, comfort and privacy, photonics is the key tool for delivering the necessary performance, resilience and security in data services and network infrastructures. To handle vastly greater flows of data, IT systems will be much more powerful than today while using less energy, thanks to the emerging shift to high-performance optical and quantum computing.

Market outlook and disruption potential

We will soon live in a world where everything that can be connected is connected. To cite just one number from a World Economic Forum study: As early as 2022, one trillion sensors will be connected online. Connectivity and digitisation, a vastly more powerful internet infrastructure and the emergence of autonomous robots and rtificial intelligence will fundamentally transform the nature of work – as well as every other area of human activity. Managed well, this transformation will open up tremendous new opportunities for Europe's citizens and businesses.

To get there, however, significant technological obstacles still have to be overcome. In light of the quantum leaps in computational speed, data volume and network capacity that will be required by always-on connectivity and new data-hungry services, the current technology of semiconductor microelectronics is approaching its physical limits. Reliability, low latency and 100% coverage are becoming increasingly important in machine-to-machine communications, not only for Industry 4.0 applications, but also for new connectivity-based services such as fully automated driving. Growing threats to digital security and privacy require new approaches to encryption, authentication and shielding of networks. With data centre traffic consuming nearly 2% of all electricity used today, there is an urgent need for a paradigm shift to greener IT technology.

Photonics is already crucial to mastering these enormous technological challenges. The transition from electrical wires to fibre optics has allowed unprecedented jumps in broadband speed and data volumes. Photonics is helping to build greener IT: Since light can travel vast distances through fibres, fibre optics consumes only a fraction of the energy used by conventional technology that transports electrons via copper wires. In the future, photonics will thus lay the basis for a faster, greener and more secure internet infrastructure, which in turn will unleash the development of countless new services and business models. A more secure and resilient network infrastructure is also an essential prerequisite for Industry 4.0 and the European Digital Single Market.

While European companies have only a small share of consumer electronics markets such as those for cameras and displays, they occupy a strong global position in IT components, network infrastructure technology and IT manufacturing technology – three key areas that are driving the digital economy forward. In particular, photonics technology leverages a European telecommunications infrastructure

market worth EUR 350 billion annually, thereby impacting more than 700,000 jobs. As an enabler, telecommunications technology plays a vital role in enhancing other sectors' business growth.

Pioneering solution: optical computing for quantum leaps in speed, resilience and efficiency

The silicon semiconductor chip is nearing a physical boundary dictated by the properties of electrons. Beyond that boundary, significant increases in speed and performance can no longer be achieved. One of the most promising post-semiconductor technologies is optical computing, where photons replace electrons as the medium for signalling and processing information in all areas of IT, including microprocessors – a technological quantum leap that will expedite significant increases in speed, data density and energy efficiency.

"It is now possible to build optical components on a micro scale, a step comparable to the transition from conventional electronics to microelectronics in the 1960s."

This is no longer theory. It is now possible to build optical components on a micro scale, a step comparable to the transition from conventional electronics to microelectronics in the 1960s. These photonic components are already being deployed in telecommunications – in the transceivers that translate between electronic and fibre optic hardware, for example. Using optical circuits at the microprocessor level is significantly more complex, but innovation is advancing on a broad front. Current developments in Europe and the United States focus on optical connectors between circuit boards, removing a significant bottleneck in computing speed. Within a decade, the same is envisioned for chip-to-chip. The ultimate leap would be to abandon these "optoelectronic" components in favour of fully optical microprocessors, in which all electronic signals are replaced by photons, even inside the chip. A first step in that direction will be purpose-built optical computers designed to meet specific needs, such as accelerating the solution of optimisation problems like the "travelling salesman".

Europe has several growing clusters in optical computing research and development. The EU also has a powerful ecosystem of companies and R&D facilities in silicon-based microprocessor production technology whose global lead could be threatened by disruption in a post-electronic age. The challenge in the transition to optoelectronics involves not only technological innovation, but the development of new modes of mass production capable of integrating microelectronic and photonic functionality at the required speed, cost and reliability levels. This will take large-scale investment and industry-wide coordination. Beyond that, the transition to fully optical computing will require even greater efforts. The prize, however, will be market leadership in what is likely to be one of the most promising new technologies of the 21st century.

Innovation pipeline in photonics for IT

The shift from electronic to photonic technology in telecommunications and other areas of IT is taking place on multiple fronts. As it progresses, it is building the basis for a steady stream of bandwidth-hungry products and services. Other emerging technologies are equally promising:

- Quantum encryption using photons will extend current algorithm-based encryption technology, taking cyber-security to the next level.

- Optical wireless communications (OWC) is seeing a lot of interest as an additional method of broadband connectivity. OWC is also being developed as a way to provide telecommunications access in rural and remote regions using high-altitude balloons or drones, usually in combination with conventional wireless technologies.
- Photonic data storage is another technology on the path to fully optical computing. An optical memory involving no electronics at all would allow very large amounts of data to be read or written at a much faster speed than current technology.
- Organic optoelectronics, too, is an area where product developers are working to transcend the physical performance limits of conventional microelectronics. The first products in the pipeline include data centre components that use polymer-based optical waveguides to build a higher density of photonic circuits, thereby enabling higher data speeds at lower cost.

The way forward

To grow the market for next-generation photonic information and telecommunications technology, substantial hurdles must still be overcome.

Implement 5G networks using fibre-optic backbones as the enabler for new connectivity-based services and business models. Europe was a pioneer in mobile telephony in the 1990s. Recently, however, some member states have been slow to build out broadband wireless networks, and have fallen behind in the growth of mobile services.

Bring broadband access to every village. Be it through mobile or terrestrial broadband, reliable and affordable high-speed internet access for all European businesses and citizens – not just those in the major urban corridors – is an absolute priority for growth and prosperity in the digital age. Many member states have fallen way behind the global leaders and will struggle to implement a fully digital economy.

Raise Europe-wide cyber-security standards to build a safe and secure digital society. This requires that all member states implement strict regulations and standards to raise citizens' trust in the security of their data and networks. For this reason, recent proposals to strengthen Europe's cyber-security body, the European Network and Information Security Agency (ENISA), should be implemented and their scope widened.

Facilitate collaboration and establish pilot production lines through industry-wide coordination and public support. A crucial obstacle to the next generation of fast, safe and secure optical computing technology is bridging the gap from prototyping to mass production, which is a larger-scale challenge than many other areas of photonics innovation.

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Linking big ideas
Photonics as a driver of the knowledge society

Our mission:
photonics as a flagship science for innovation

"In the future, every child in Europe should know about the many ways that light can be harnessed for innovation."

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In 2030, photonics will be a pillar and driver of the knowledge society, playing an instrumental role in the creation and dissemination of knowledge and ideas. At the same time, educators, students, governments, companies and ordinary citizens across all disciplines will be increasingly aware of the opportunities and potential inherent in utilising light for the benefit of humankind.

Educating for a future of innovation and growth

As we wrote in the preface to this report, many already consider photonics to be the flagship technology that will power innovation in the 21st century, just as electronics did in the 20th century. However, to fully exploit the opportunities and potential of light-based science to transform lives, create jobs and foster growth, and to help us reach our overriding societal goals, we must change the way we educate, the way we innovate and the way we transfer skills.

First, stakeholders must build awareness among educators, media leaders, policymakers, politicians and investors. Even the European corporate sector is often unaware of how new photonics-based technology can solve some of the biggest business challenges. In the future, every child in Europe should know about the many ways that light can be harnessed for innovation.

Second, we need to start training tomorrow's innovators and specialists today. That will involve creating a platform for public-private collaboration to define new professions in photonics, required skill sets, and integrated curricula for universities, engineering colleges and vocational schools. Just as important as imparting knowledge and skills is nurturing greater awareness of – and creating opportunities for – entrepreneurship.

Third, we must break down traditional silos in knowledge disciplines and business sectors. Innovation in photonics is strongly interdisciplinary, cutting across the boundaries of physics and chemistry, engineering and materials science, IT, medicine, art and design. Stakeholders and policymakers should help build strong interdisciplinary networks in higher education and training, in research and development and across industries.

Fourth, the gender gap must be closed. All public and private actors must join forces to make science, technology, engineering and mathematics (STEM) education and professions more attractive to women. This is not only a matter of equal opportunities: It is an urgent economic imperative. The European photonics industry alone will need 80,000 new specialists in the coming years. Without highly qualified women, we will not have the skilled workforce we need to harness the power of light.

Lastly, Europe's citizens should be involved in all these efforts. The public and private sectors must engage citizens in a broad and inclusive debate about technological, economic and societal change. The next

"3D visualisation and augmented reality will make learning and the exchange of ideas easy, effective and fun."

phase of technological development will increasingly be accompanied by ethical issues, such as those that touch on machine-to-machine communication and artificial intelligence.

In all these efforts to educate, train and create awareness, photonics-based tools will themselves play a growing role. Next-generation IT will foster collaboration, access to knowledge and open innovation. 3D visualisation and augmented reality will make learning and the exchange of ideas easy, effective and fun.

Committed to success
A photonics agenda for Europe

Emerging innovations in photonics are at the core of Europe's efforts to resolve the great societal, technological and economic challenges of our day. Photonics technology will help Europe build a truly digital economy, keep an ageing population healthy and productive and adopt a more sustainable approach to the use of resources.

As the European photonics industry rises to these challenges, it will continue to create jobs and add value at rates faster than the economy as a whole. At the same time, photonics products and services will boost growth throughout the economy.

To ensure that Europe can sustain and expand its strong market position in photonics in an era of fierce global competition and accelerated technological change, and to speed up innovation at the transnational level, a number of significant barriers must still be torn down. The actions that must be taken are outlined here in a 12-point agenda for European and member-state policymakers:

1. **Create and implement a European strategy for photonics leadership** that focuses on mission-oriented breakthrough innovations and large-scale collaborative projects across industries and sectors. A coordinated strategy involving all public and private stakeholders will create the momentum and unleash the broad spill-over effects needed to address global challenges, exploit future markets and create jobs in Europe. As a foundation for future innovation, basic science and research infrastructure should be integrated in this roadmap.

2. **Build a truly European lab-to-fab infrastructure** for accelerating innovation and competitiveness. Europe needs to speed up the uptake of technology and its translation into new products and services. Europe is strong on mastering photonics technologies, so we need to continue building on this strength in order to create disruptive new products and market opportunities. The further buildout of prototyping services and manufacturing pilot lines would help SMEs across Europe to speed up their innovation processes, as would shared assets in research and manufacturing. At the same time, EU and national R&D programs should have a sharper focus on prototyping and market entry.

3. **Boost opportunities for entrepreneurship** in the photonics sector. Access to risk finance must be improved by establishing a Europe-wide fund for photonics start-up, growth and bridge capital. This could take the form of public matching funds that incentivise and leverage private venture capital.

4. **Educate and train tomorrow's specialists** today. Measures should include a coordinated public-private plan to define skill sets and curricula for professions in photonics. The harnessing of light should be a flagship science in schools, universities and across the education system.

5. **Open up current subsidy regimes** to new technologies. Emissions abatement schemes such as member states' feed-in tariffs should be adjusted to better support efficiency gains. Lighting, for example, is a far more cost-effective source of abatement than certain currently subsidised technologies.

6. **Remove barriers to innovation by applying smart regulation.** European and member-state policymakers should review and adjust regulation to actively incentivise disruptive innovation. Healthcare systems need to be more open to new technology. New standards for the industrial internet must be established. Certification regimes must be strengthened to promote efficiency and the circular economy.

7. **Accelerate the buildout of 5G and terrestrial broadband.** Ubiquitous connectivity based on fibre-optic backbones and end-to-end optical switching is the fundamental prerequisite for a fully digital, efficient, innovative and competitive European economy.

8. **Strengthen control over data and privacy standards.** A healthy balance must be struck between data protection and the ability to innovate using state-of-the-art "big data" methods.

9. **Coordinate cyber-security efforts** in order to protect our networked future from crime, industrial espionage and sabotage by state actors. Both the Industrial Internet and the Internet of Things open up an almost infinite number of potential entry points. SMEs are especially vulnerable and may need incentives and support.

10. **Turn the public sector into a lead innovator** committed to pioneering new, energy-efficient and sustainable products, services and processes. By utilising their buying power, governments can accelerate the spread of breakthrough technologies such as smart lighting and electric vehicles.

11. **Complete the Digital Single Market** to open up digital opportunities for consumers and businesses and strengthen Europe's position as a world leader in the digital economy. A fully digitised economy will not only accelerate growth across every industry and sector, but also boost demand for photonics technology.

12. **Establish a strong digital innovation ecosystem** in photonics that ties together all the relevant public and private actors in order to facilitate innovation and collaboration. These actors include universities and research labs, start-ups, SMEs and multinationals. Key actors such as healthcare systems, transport operators, insurance companies and telecoms players should be grafted into these hubs and clusters where appropriate, as should the lab-to-fab infrastructures outlined above.

Photonics is the bedrock of future innovation in Europe. It's time to harness the power of light.

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