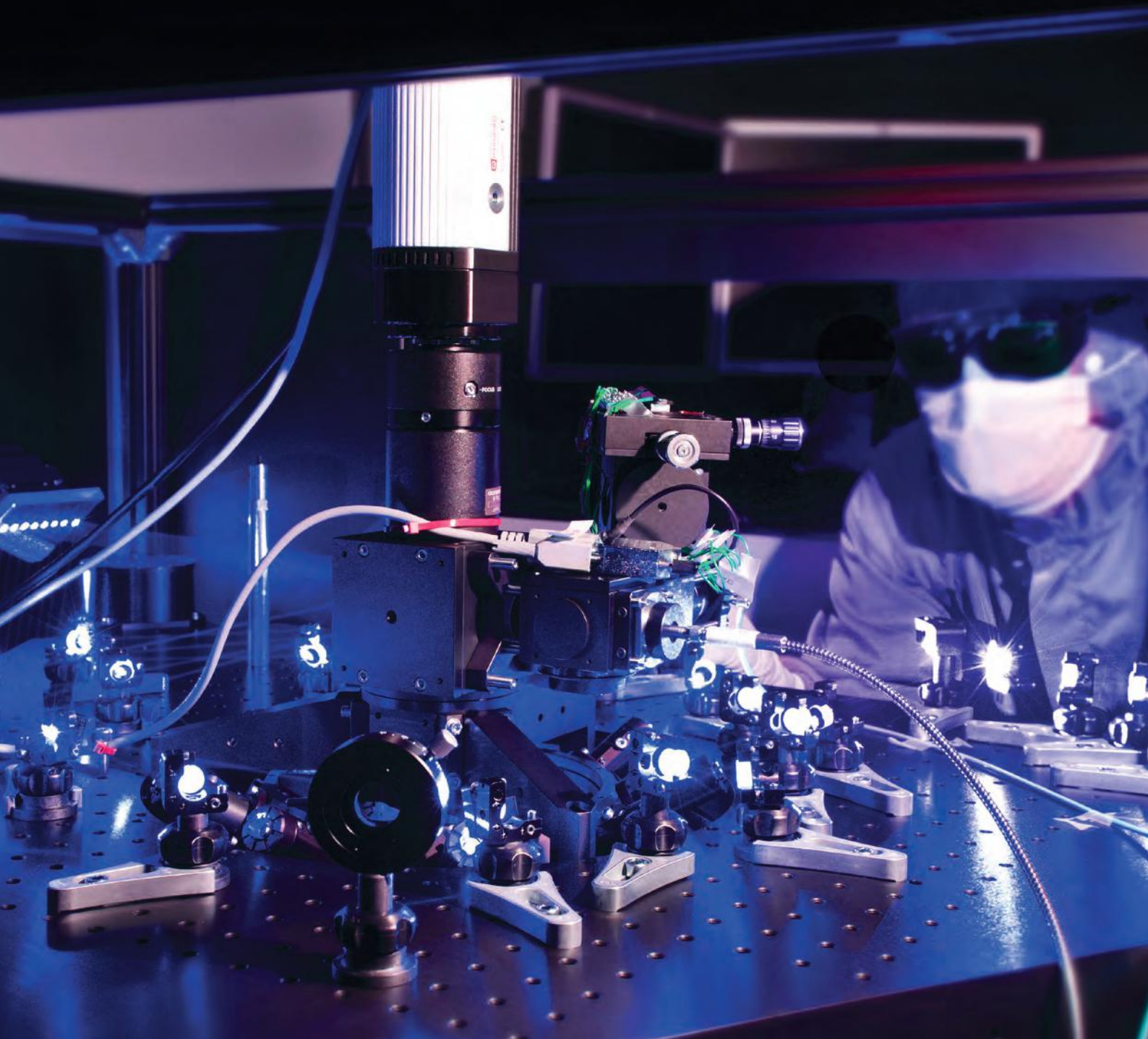
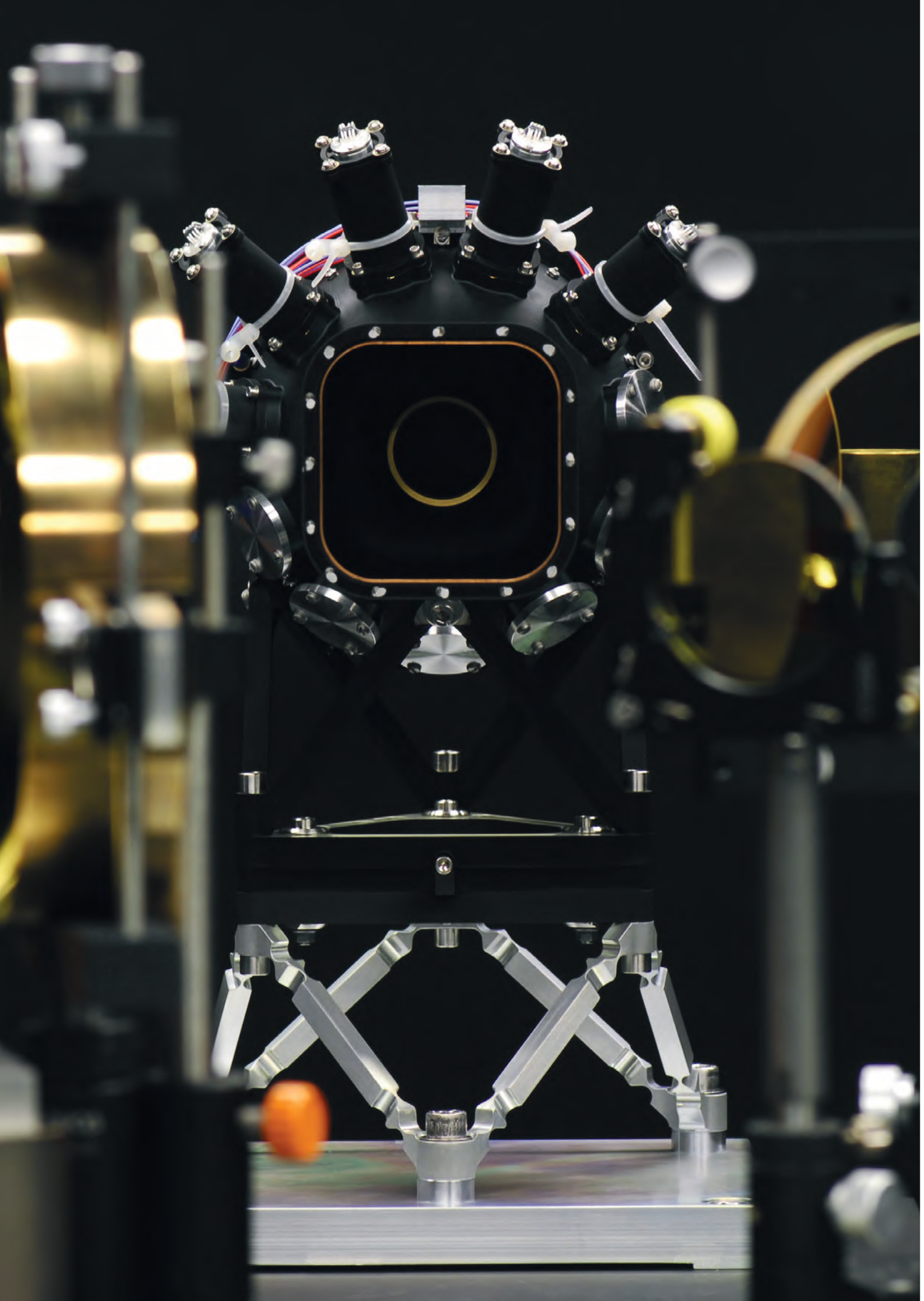
NATIONAL AGENDA **PHOTONICS**



NATIONAL AGENDA PHOTONICS

July 2018



CONTENTS

Picture left: Calibration of the James Webb Space Telescope (NASA, TNO)

SUMMARY

Photonics is the key technology that uses the properties of light for a wide range of applications such as sensing, data communication and production technology. Photonics plays a major role in the success of the Dutch high-tech industry and makes an important contribution to solving social challenges, for example by means of climate monitoring.

The photonics market is developing rapidly. The global photonics industry is estimated to grow by 40% over the next five years; with the Netherlands as one of the leaders in the EU. Nearly 300 Dutch companies, a large proportion of which are SMEs, work directly on photonics products, with an estimated total turnover of more than 4 billion euros.

The objective of this National Agenda Photonics is to intensify and accelerate the application of photonics technologies for solving societal challenges and creating new businesses. One of the aims is to share forces: joint initiatives and clusters are proposed, in which the Netherlands presents itself internationally as a single cohesive photonics region.

In the Netherlands, six clusters of companies and knowledge institutes have been identified for the six promising application domains.

Agenda of the future:

- The six application-oriented clusters, and two basic technology clusters, the Dutch Optics Centre and PhotonDelta, have together developed eight investment initiatives for new technology development.
- For the entire sector, the focus will be on awareness- and branding, knowledge roadmaps, skills and education.
- These activities will be implemented in an eight-year programme, which will be realised, as far as possible, by existing structures and organizations.

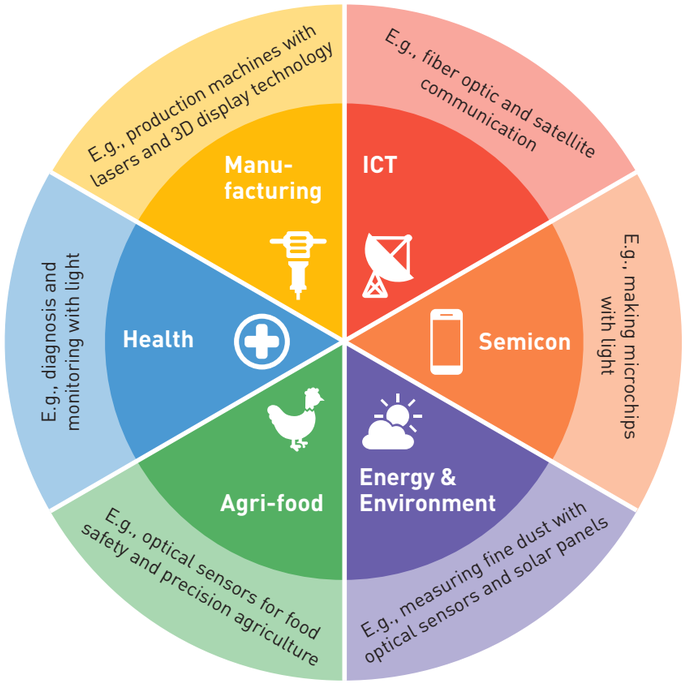
Funding

For the investment initiatives in the framework of the National Agenda Photonics, a total investment of around € 60 million per year is foreseen, which will be financed partly by the public sector and partly by the private sector. This as a reinforcement of the hundreds of millions of euros that are already being invested in photonics by the market.

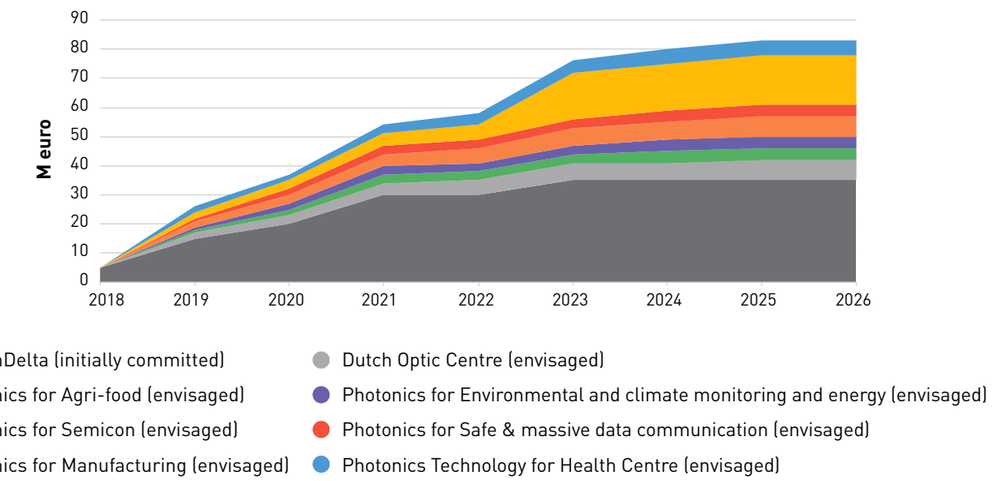
Investment initiatives

- Photonics Technology for Health Centre
- Photonics for Manufacturing
- Photonics for Semicon
- Photonics for Safe & Massive Data Communication
- Photonics for Agri-food
- Photonics for Environmental and Climate Monitoring and Energy
- PhotonDelta
- Dutch Optics Centre

Six promising clusters: Health, Manufacturing, ICT, Semicon, Energy & Environment and Agri-food



Global financing National Agenda Photonics, initially committed and intended



FORWORD

By Marc Hendrikse

The high-tech industry is of great importance to the Dutch economy. We owe a significant part of our prosperity and export position to innovative companies such as ASML and Philips, surrounded by a large segment, of varied and robust small and medium-sized enterprises.

Photonics, the key technology that enables all products and components in which light plays an important role, is a success factor for our high-tech industry, now and in the future. The heart of the machines of ASML, world leader in its field, is based on photonics technologies.

Photonics has an important contribution towards solving societal challenges. A good example of this is the satellite instruments that are made in the Netherlands for climate monitoring. Photonic components are also playing an increasingly important role in new technologies for medical care.

It is very important for the Netherlands that we invest heavily in photonics technology. The government coalition agreement explicitly mentions photonics as a key technology that is at the basis of countless new - as yet unknown - applications.

I, therefore, welcome this ambitious National Agenda Photonics. This provides direction on what needs to be done to enable an acceleration in this area, such as better international branding, leading innovation programmes and the training of suitable personnel. The public-private partnership PhotonDelta, which is now the result of a combination of forces from the national government, provinces, knowledge institutes, SMEs, industry and the top sector HTSM, is a powerful first step towards implementing the coalition agreement. This fits in seamlessly with the ambitions of this agenda and with the renewed top sector policy.

Therefore, I see this agenda as an invitation to companies, knowledge institutes and governments to participate in the acceleration of photonics. It is said that the twentieth century was the century of the electron. If the twenty-first century is to be the century of the photon, then this is the chance for the Netherlands to become an international leader.

Marc Hendrikse, figurehead of the top sector High Tech Systems and Materials (HTSM)

PhotonDelta Integrated Photonics Ecosystem

PhotonicsNL NETHERLANDS

Dutch Optics Centre a TNO and TU Delft initiative

Photonics is the technology that focuses on the generation, transport and detection of light waves and light particles, also called photons. Photonic solutions are a response to the growing need in the areas of communication, food production, living comfort, industrial digitization and health.

1 / INTRODUCTION

Photonics is a technology that is used in many products. This includes products we use every day, such as cameras in mobile phones, the internet and lighting. Despite the fact that photonics is relatively unknown to the general public, there are great opportunities in this domain for the Netherlands. This National Agenda Photonics provides insight into what these opportunities are for the Netherlands and how we can capitalize on them.

Photonic solutions are the answer to growing needs in the areas of communication, food production, home comfort and health, with a minimum of strain on the living space. The expected economic growth of the photonics industry is much higher compared to the growth of the economy in general, with growth rates for the photonics industry is estimated to be 6.4% per year until 2020[1].

It is with good reason that photonics is seen as one of the important key technologies for the future, both in the European Commission, in the Knowledge and Innovation Agenda (KIA)[2] and in the top sector HTSM, which recently published the Photonics Roadmap 2018.

The Netherlands has traditionally had a strong position in photonics. This is partly due to a wealth of experience in the development of optical instruments with which Christiaan Huygens started as early as 1690. Today's leading companies, such as Philips and ASML, have their origins in photonics, and so do a wide range of small emerging innovative companies.

It is important for the Netherlands to remain at the forefront of photonics in terms of employment, future economic growth and solving societal challenges.

This National Agenda Photonics sets out the government's ambition, as laid down in the government coalition agreement, to further industrialize and internationalize this important technology for the Netherlands. The objective of the agenda is to intensify and accelerate the application of photonics technologies for solving societal challenges and creating new businesses.

The societal challenges[2] are the starting point for the National Agenda Photonics. From this, a selection of application areas and associated clusters has been made. In consultation with the clusters, more than 75 representatives of Dutch organizations met in seven stakeholder sessions, which were used to create the basis of the market analyses and inventories of the clusters that are presented in this report.
A number of clusters have also set up investment initiatives. The final chapter of this document sets out the most important preconditions for making the agenda a success.

[1] Photonics21 (2017) Market research study 2017 – Key figures

[2] Kennis- en Innovatieagenda 2018-2021, Maatschappelijke uitdagingen en Sleuteltechnologieën. Topsectoren, 2017

2 / DUTCH DEVELOPMENTS IN AN INTERNATIONAL PERSPECTIVE

The photonics market and technologies are developing rapidly. From an international perspective, this chapter outlines the most important developments for the Netherlands.

2.1 THE NETHERLANDS' POSITION IN THE INTERNATIONAL MARKET

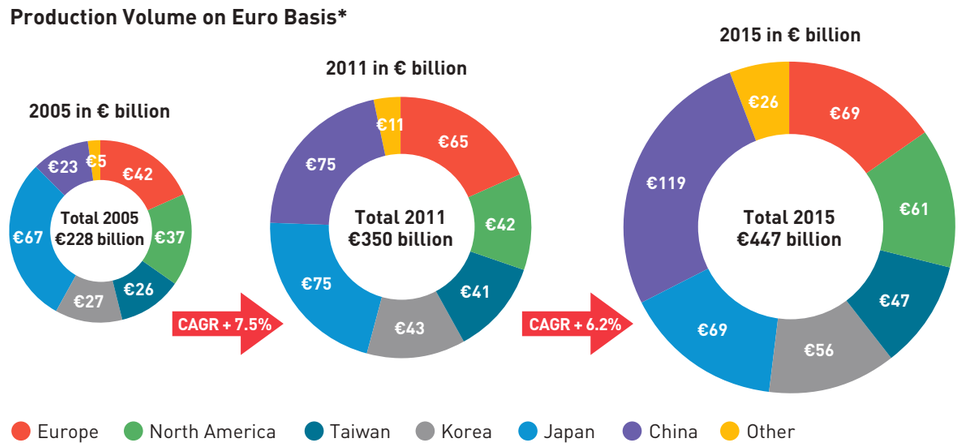
Photonics has for many years been the basis for leading companies in the Netherlands, such as ASML and Philips. Dutch photonics companies are in fourth place among the most competitive companies in photonics according to the SPIE Industry Update 2018. However, the market share of the Netherlands in the total world market is limited.

High-growth market

Photonics is a large and fast-growing market. In 2015, the global photonics market was worth € 447 billion (*Figure 1*). In ten years, this market has almost doubled. The market size is estimated to increase to € 615 billion in 2020 (6.4% growth per year).[3]

FIGURE 1

Global photonics industry: Strong growth above global GDP: from 228 billion euro in 2005 to 447 billion euro in 2015[3]



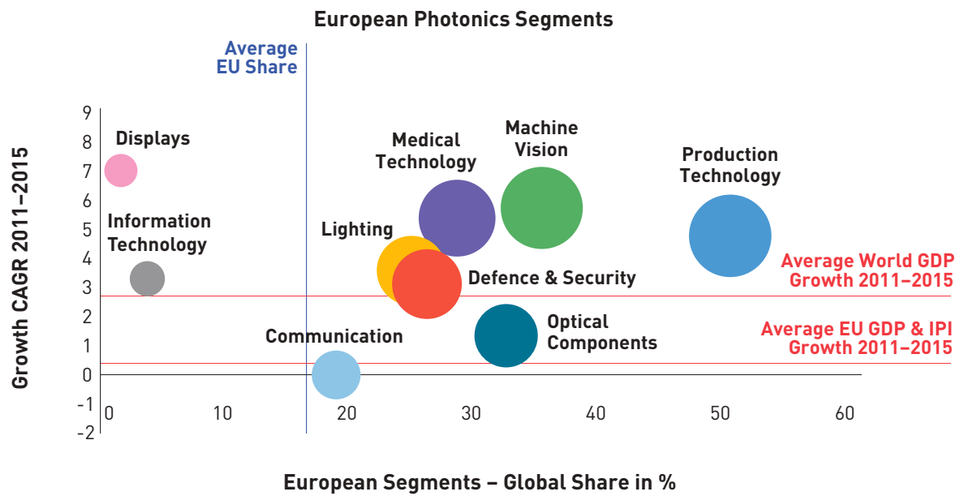
*including Photovoltaics, which is not subject of the PPP

[3] Photonics21 (2017) Market research study 2017 – Key figures

Picture left: Waveguide microPL (TU/e)

FIGURE 2

Growth European photonics segments



Source: Photonics21 (2017) Market research study 2017 – Key figures

China is the largest player and is responsible for more than a quarter of the photonics production. This is followed by Europe (15%), Japan (15%) and Korea (13%). Germany is the largest producer in Europe with 41% of the European photonics production. The UK and the Netherlands both represent 13% of photonics production in Europe.

In the period 2005-2015, the Netherlands was the fastest growing photonics region in Europe with an average growth rate of 7.3% per year.[3] This is mainly due to ASML's revenue growth.

The Netherlands and Europe have a large share in production technology

Almost all European photonics segments grew faster than GDP in the period 2011-2015. The strong growth over the years is represented in *figure 2*. These segments will continue to grow strongly in the coming years.

Within Europe, the Netherlands is the most important player in the application of photonics in production technology. More than 50% of the production technology is made in Europe. Europe and the Netherlands have a small share in the production of displays and information technology. Asia, and China in particular, has taken over a large part of the production of displays, optical components and modules, among others, from Europe. In the production of optical components, for example, the Netherlands is only seventh in the world.

Dutch Innovation

R&D is the most important source of growth for the photonics sector in Europe and the Netherlands. Technological developments are taking place at a rapid pace and innovation is essential to stay ahead of the competition. Nearly 10% of the turnover in the photonics industry is invested in R&D, which amounts to approximately 10 billion euros per year[4].

PHOTONICS: A KEY ENABLING TECHNOLOGY

Photonics has been appointed by the European Commission as one of the key enabling technologies (KETs). Europe is investing heavily in photonics. In the period 2014-2016, the European Commission invested almost 278 million euros in PPP projects in the field of photonics. Nearly half of this budget is for industry. Of this, 49 million euro was spent on pilot lines.

Photonics21

In November 2013, the PPP "Photonics21 Association" was established as a contact point for the European Commission. With this PPP, the European Commission has committed itself to invest in Europe with the aim of generating European industrial leadership and economic growth, highly skilled personnel and new jobs for young people.[5] The European Technology Platform Photonics21 has more than 2,500 members and publishes roadmaps[6], market studies and vision papers, among others. Partly as a result of the European KETs strategy, several countries are in the process of setting up their own photonics roadmaps.

Dutch companies and institutes stand out on the international market because of their high level of knowledge and entrepreneurial culture. Dutch parties are seen as skilled in R&D and high-end production.

2.2 ECONOMIC IMPACT OF PHOTONICS

Employment and economic growth

Photonics is a fast growing sector and therefore an important driver of employment and economic growth in the Netherlands.

An estimated 290 companies that are based in the Netherlands are active in photonics[7], with a total turnover of EUR 4.2 billion in photonics.[8]

The largest part of this turnover comes from the large international companies ASML, Océ-Canon, Signify (Philips Lighting), Philips Healthcare and Prysmian Group (optical fiber cables and systems for energy and telecommunications). In 2015, more than 20,000 employees were employed in the development and production of photonics applications.[9]

The future looks bright. In the coming years, more than 85 percent of companies expect to achieve annual job growth of 5 to 20 percent or more.[10]

4 Jobs and Growth in Europe – Realizing the Potential of Photonics. PPP Impact Report 2017 (2017). Photonics21

5 Photonics21: https://www.photonics21.org/about-us/photonics-ppp/

6 Strategic Roadmap – Towards 2020 – Photonics Driving Economic Growth in Europe

7 Combination databases of EPRISE, PhotonicsNL, EPIC, DOC and Dutch Photonics

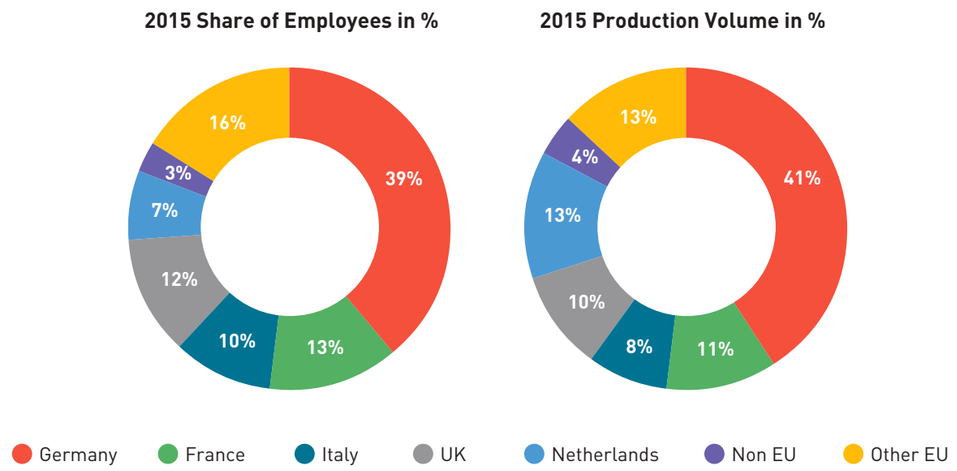
8 Combination Photonics21 (2017). PPP Impact Report 2017 & Photonics21 (2017) Market research study 2017 – Key figures

9 This number is derived from Photonics21. The definition includes persons working in companies that produce photonics products. Research institutions are not included in this.

10 PhotonicsNL and ABN-AMRO (2017), 'Nederlandse industrie ziet het licht met fotonica'

FIGURE 3

European photonics industry overview by country of employment and production



Source: Photonics21 (2017) Market research study 2017 – Key figures

Regional impact
The high growth expectations are reflected in the initiatives taken at the regional level. The provinces of Noord-Brabant, Overijssel and Gelderland collaborate in order to build on their advantage in the field of integrated photonics. In the long run, this should create more than 7,000 new jobs in the region[11].

Maintaining competitiveness of the Dutch economy
The leverage of photonics on the manufacturing industry and end markets is considerable. In the EU Report Leverage of Photonics[12] concludes that around 10% of the European economy depends on photonics for its competitiveness, both in terms of markets and jobs.

Photonics is an enabling technology and enables innovative solutions in a wide variety of sectors. Photonics is, therefore, a driving force for maintaining the competitiveness of the Dutch economy as a whole.

2.3 RELATIONSHIP WITH SOCIETAL CHALLENGES

Photonics has a broad impact not only on the economy, but also on society. Photonics enables new solutions for telecommunication, lighting, energy and food production, data processing, sensing and monitoring.[13] Sensors are used for ultra-sensitive detection of substances and in extreme conditions. In addition, autonomous energy-efficient sensors are being developed.

[11] Regioradar (2017). Samenwerking drie provincies voor versterking fotonica-industrie.

[12] Photonics21 (2011). Leverage of Photonics

[13] Kennis- en Innovatieagenda 2018-2021, Maatschappelijke uitdagingen en Sleuteltechnologieën. Topsectoren, 2017

Photonic technologies make an important contribution to solving almost all societal challenges. A few examples are:

- **Health and Care**: photonics diagnostics via handheld devices, sensors for minimally invasive surgery, high-quality video connections for robot-assisted operations.
- **Energy and CO_2**: ultra-efficient light sources and solar cells ("green photonics"), reduction of energy consumption in data centers through the use of integrated photonics chips.
- **Secure society**: sensors and image processing technology for surveillance.
- **Climate and Water**: Optical measurement of air and water quality from satellites and ground stations.
- **Mobility and transport**: photonics-based sensor technology in self-driving vehicles for communication, monitoring, warning and visibility.
- **Agriculture and food**: satellite earth observation for precision agriculture, optimal lighting in horticulture, vision for phenotyping and growth monitoring.

2.4 NEW TECHNOLOGY DEVELOPMENTS IN THE NETHERLANDS

Currently, A wide range of new photonics technologies are rapidly developing that offer opportunities for the Netherlands:

- **More powerful light sources and other wavelengths**
  For example, VCSELs[14] for fiber optic telecommunications and Extreme UV (EUV) sources for more accurate chip measurement and fabrication.
- **New forms for optical components and optics on a chip**
  For example, new forms of mirrors, lenses and chips such as free-form optics, micro-optics, adaptive optics and integrated photonics.
- **Manufacturing techniques for ultra-compact optical systems in large series**
  For example, improved manufacturing techniques such as 3D printing, injection molding, diamond turning and robot polishing.
- **New synthetic materials**
  For example, semiconductors, glass types, meta-materials, photonics crystals, nanostructures, quantum dots, and new biological materials.
- **Smaller, more energy-efficient sensors**
  Photonic structures, often integrated into fibers or optical circuits, are used, for example, for measuring displacement, voltage or acoustic waves and for 3D imaging systems for autonomous vehicles.
- **New technology with a combination of photonics and software**
  For example, further development and application of Virtual Reality, Augmented Reality and Computational Imaging (CI). Computational Imaging, also referred to as 'lensless imaging', uses computer algorithms to improve the performance of an imaging system while maintaining the same specifications for the lens.

2.5 CONCLUSION: STRONG COMMITMENT TO UNIQUE INTERNATIONAL NICHES AND BREAKTHROUGH INNOVATIONS

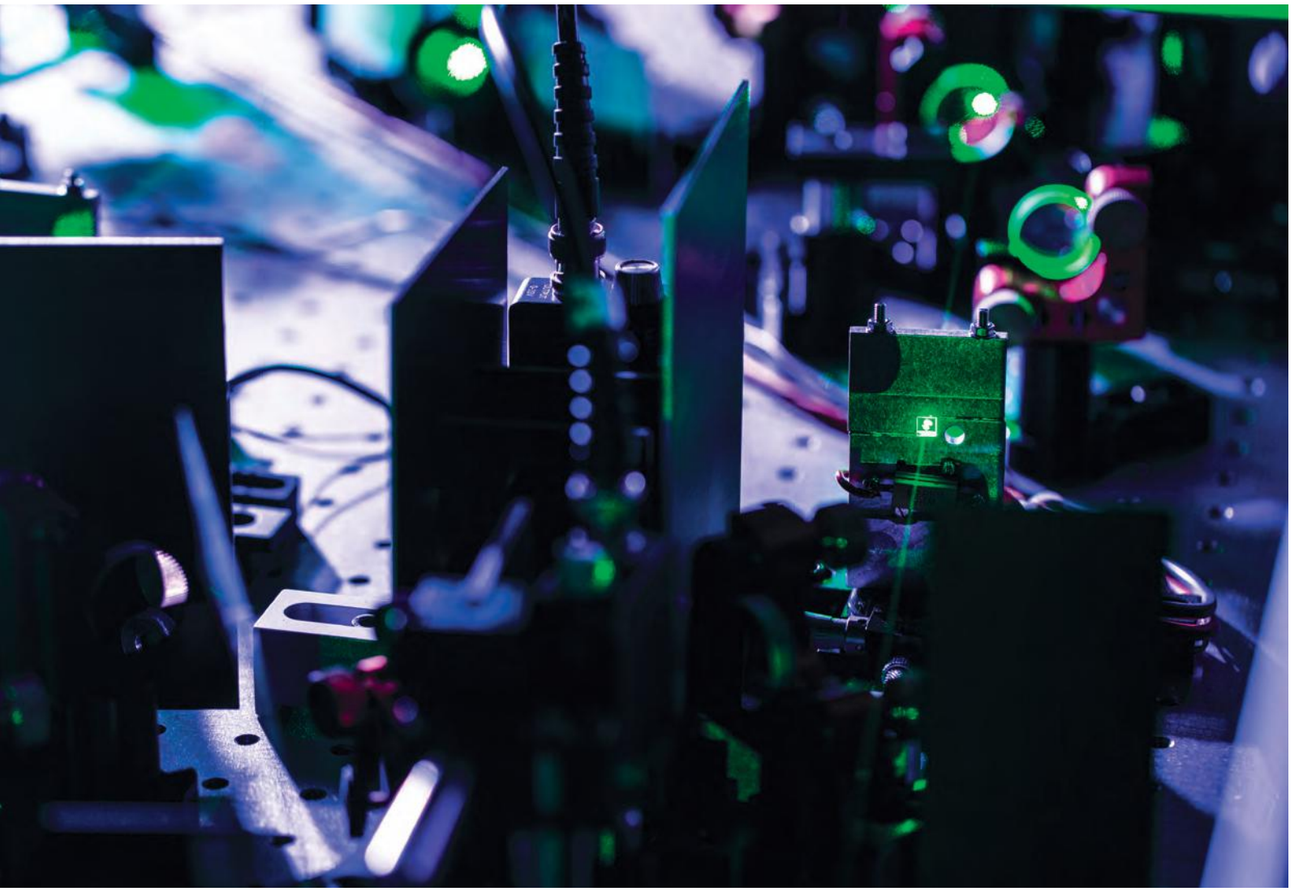
Growing international markets offer plenty of opportunities for photonics. Europe has a leading position in photonics, particularly in manufacturing technology and industrial image processing, and competition from Asia poses a serious threat. The European Commission is fully committed to photonics, as one of the Key Enabling Technologies, to ensure Europe's competitiveness.

[14] VCSEL: Vertical cavity surface emitting laser. Lasers each of a few micrometers in size that are used as light sources in the telecom industry in data centers due to their low energy consumption. These lasers offer new perspectives for laser processing of materials.

Photonics is an essential key technology in solving almost all societal challenges and is also an important driver for employment and economic growth in the Netherlands. Not only in the photonics sector itself, but also by enabling breakthrough innovations in other sectors.

Technology development in photonics is proceeding at a rapid pace. The Netherlands has an excellent starting position - with leading companies and strong positions in knowledge and technology development, but compared to the US and China, investments in production facilities are limited. To ensure the industrial leadership position in the future, new steps need to be taken, for example in specific niches: technology areas such as biophotonics, integrated photonics in Indium Phosphide and TriPleX, fiber sensors and computational imaging. Now is the time for his next move.

Chapter 4 examines the promising application areas of photonics for the Netherlands and the challenges that need to be tackled, but first, in chapter 3 we will zoom in on the Dutch photonics landscape.



EUV Generation and Imaging (ARCNL)

3 / THE DUTCH PHOTONIC LANDSCAPE

Photonics has an impact on the Dutch economy and society. This chapter provides more insight into the players that make this possible.

3.1 COMPANIES

An estimated 290 companies in the Netherlands are directly or indirectly linked to photonics. The photonics value chain is characterized by major players from the Netherlands: Signify (Philips Lighting) in the lighting industry, Philips Medical in medical photonics and ASML in lithography machines.

In addition, NXP, Airbus and Océ-Canon have important activities in the Netherlands. Furthermore, the landscape consists of a large number of smaller, innovative SMEs.

Worldwide, we see the same distribution. According to SPIE (2018), more than 75% of optical component manufacturers are SMEs with an annual turnover of less than € 8.5 million.[15]

Examples of successful Dutch products

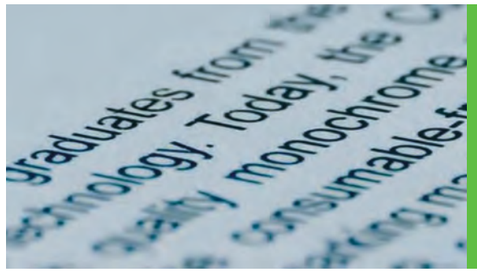
Fluorescence Lifetime (FLIM) cameras are used in cancer research to, among other things, measure the efficacy of chemotherapy within a few days compared to more than 2 months with existing techniques. (Lambert Instruments)

Spectroscopy solutions are used in both harvesting and manure distribution. (Avantes)

[15] SPIE (2018). SPIE Industry update

Photonics offers solutions for the entire care chain, from healthy living and prevention, to diagnosis and treatment and home care, such as digital pathology. (Philips)

Augmented Reality platform technology is used in the healthcare sector: as a result, a patient no longer needs to leave home to be checked, the hospital can already monitor the patient while in the ambulance and a situation can be quickly assessed remotely in maternity care. (GemVision)



Laser-based monochrome printing technology that can print on multiple substrates without consumables or coatings. Inkless technology is a revolutionary new step, especially when it comes to printing on paper objects. (Tocano)

3.2 RESEARCH INSTITUTES

The Dutch research institutes are internationally distinctive in photonics. The quality of scientific publications in the field of photonics is well above the world average.[16] Dutch research institutes are active across the entire spectrum of photonics technologies: from imaging to optical communication. There is active involvement from University of- Leiden, -Utrecht, -Amsterdam, -Groningen, -Wageningen, -Twente (MESA+), TU Eindhoven (Institute for Photonic Integration), TU Delft, Radboud University, VU Amsterdam, and several University & Medical Centers. All five TO2 institutes are active in the development of photonics-based systems.

The Netherlands Organisation for Scientific Research (Dutch: NWA) is committed to a strong scientific community within the Netherlands. Through NWO, the photonics activities are clustered around the domains TTW (Memphis II program) and ENW (fundamental programs in physics, chemistry, astronomy and life sciences) and the NWO institutes. Examples of programmes in the ENW domain are LINX, Physics for Nano Lithography (PNL) and Nanophotonics for solid-state lighting (NSL). The NWO manages six research institutes for the sustainable coordination of scientific fields in photonics: ASTRON, SRON, AMOLF, Nikhef, Differ and ARCNL.

[16] Elsevier (2018). Quantitative Analysis of Dutch Research and Innovation in Key Technologies (in press)

TABLE 1

TO2-Institutes

TO2-Institute	Application of photonics
NLR	Optical visualization of flow around an object, fiber based gyros, laser material interaction
DLO	Spectroscopy for disease recognition of plants and crops, nutrient measurement in food
MARIN	Optical systems for measuring vessel dynamics
Deltares	Fibre Sensors and Spectrometers for measuring water quality
TNO	Optical systems such as climate satellites, astronomy, sensors for the semiconductor industry, vision systems for defense, optical systems for the oil and gas sector and for the manufacturing industry, and solar cells

Collaborating for scientific, social and economic impact
The cooperation between the various knowledge institutions is based on the content and expertise, thus contributing to the scientific, social and economic challenges of our time. In addition, cooperation between knowledge institutions and industry is essential in order to deliver well-trained engineers and technical designers and to conduct leading international and socially relevant research.

Ben Feringa (RUG) won the Nobel Prize for Chemicals in 2016 with a "Molecular Motor", a light-propelled rotating molecule.

3.3 NETWORKS AND PARTNERSHIPS

Collaboration between knowledge institutes, companies and the public domain is an important factor for strong competitiveness. Most of the photonics companies and institutes are connected to one of the regional, national and European networks.

The three most relevant photonics networks in the Netherlands are:

PhotonicsNL
PhotonicsNL is the Dutch portal for opticians and photonics experts and is a unique community for photonics in the Netherlands.

PhotonicsNL stimulates innovation in the photonics domain by enabling collaboration and cross-fertilization between companies and different sectors. This emphasizes the value of photonics for the economy and strengthens the knowledge of photonics at all levels of education.

Dutch Optics Centre
Dutch Optics Centre (DOC) is a consortium of knowledge institutes with close involvement of more than 150 Dutch high-tech companies. Starting as an initiative from TNO and Delft University of Technology, a strong Dutch ecosystem in optomechatronics is being formed through joint R&D, shared high-tech facilities and infrastructure, the development of prototypes and the formation of product consortia. DOC focuses on applications for imaging, spectroscopy and metrology.

TABLE 2

Alliances in the Netherlands

Alliance	Collaboration Between	Research Areas
ARCNL	VU, UvA, NWO, ASML	EUV source development, optical metrology, laser systems, spectroscopy, computational imaging and optics in general
Holst Centre	TNO, IMEC	Flexible (medical) imaging equipment for large surfaces, free form lighting, signaling and sensors, virtual reality displays
Solliance	ECN, TNO, IMEC, Holst centre	Research into solar cell production technology
MESA+	UT	Nanotechnology
IEEE Photonic Society Benelux		Lases, optical equipment, optical fibers, associated light technology
LaserLaB	VU, UvA, Amsterdam UMC	Interaction of light with matter, fundamental research on atoms and molecules in living matter
AMOLF		Nanophotonics, Biophysics

By stimulating and facilitating networking opportunities between scientists from universities, knowledge institutes and industry experts, the development of innovative technologies is accelerated.

PhotonDelta
PhotonDelta was set up from TU Eindhoven in collaboration with TU Twente and TU Delft and brings together industry and universities to promote integrated photonics in new and emerging markets. The aim is to introduce photonics chip technology, from design to packaging and testing, into an industrial ecosystem of companies capable of serving markets across the spectrum of social issues.

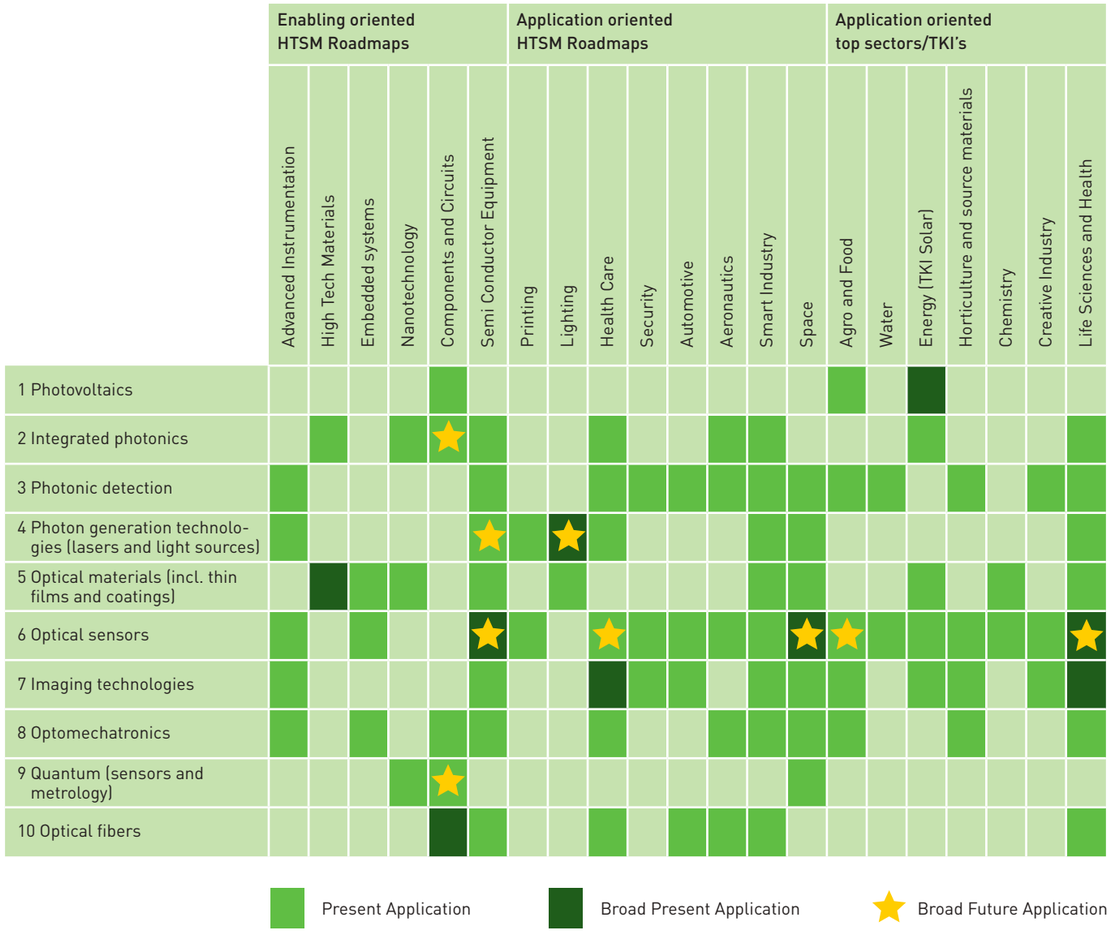
In addition, PhotonDelta is putting the Netherlands on the European map as a hotspot for integrated photonics with a Digital Innovation Hub.

Recently, these networks have joined forces. They work together on activities relating to promotion and acquisition for the Dutch photonics industry, for example during conferences and trade missions, on coordinating research directions and on policy in consultation with the government. The investment programme for the PPP PhotonDelta was also drawn up in close cooperation between the parties.

In addition, a number of other partnerships are active in the field of photonics in the Netherlands (*Table 2*).

TABLE 3

Top 10 photonics crossovers with top sectors and roadmaps in the Netherlands



Source: HTSM Photonics Roadmap 2018

3.4 KNOWLEDGE AGENDAS, TOP SECTORS AND ROADMAPS

Photonics has an impact on most relevant Dutch knowledge agendas, such as the Knowledge and Innovation Agenda (KIA), the Top Sectors Roadmaps and the National Science Agenda (NWA). These agendas link the policy agendas, the business community and science.

Photonics connects to many of the 25 NWA routes mentioned in the NWA agenda. Photonics, for example, makes a significant contribution to the NWA routes 'Sustainable production of healthy and safe food', 'Healthcare research, prevention and treatment', 'Building blocks of matter and foundations of space and time' and 'Quality of the environment'.

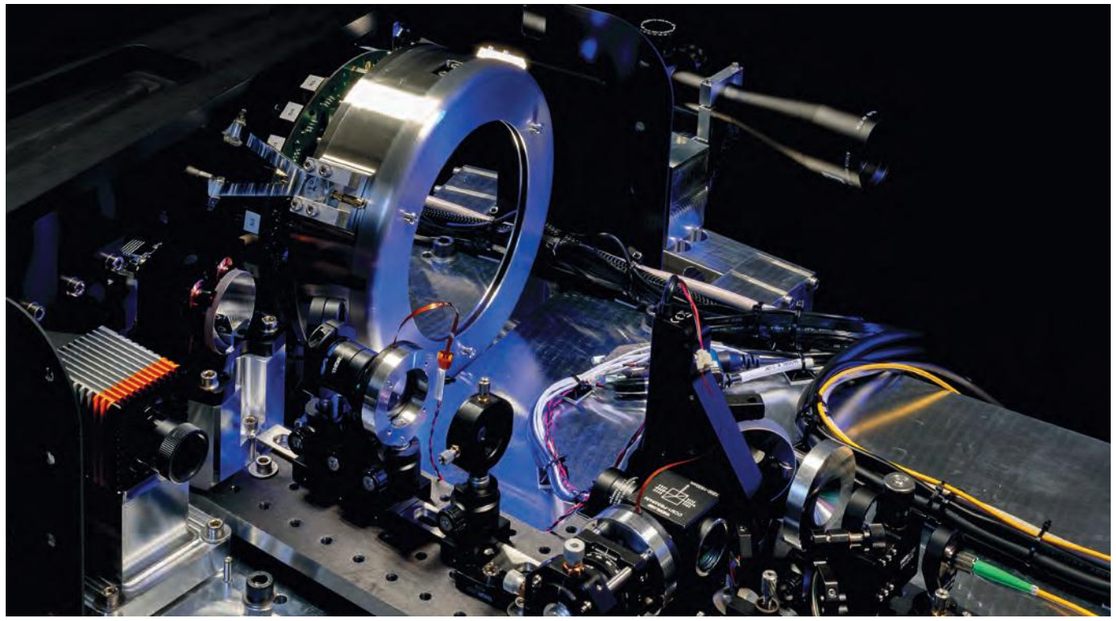
The National Agenda Photonics specifically builds on the HTSM Photonics Roadmap 2018.[17] This roadmap contains an elaboration of the application of photonics for nine societal challenges with examples from industry and science. The relationship with other roadmaps and top sectors is also established (*Table 3*). The Photonics Roadmap does not yet contain a concrete plan for the targeted strengthening of the Dutch photonics ecosystem or a coordinated acceleration of innovation. This National Agenda Photonics gives substance to this.

3.5 CONCLUSIE

Photonics is a broad field of study, which is vibrant in the Netherlands. It is estimated that 290 companies and another 30 research groups and networks in the Netherlands are linked to photonics and contribute directly and indirectly to economic and social impact.

Most of these organizations are linked to one of the many initiatives, networks, roadmaps and knowledge agendas.

For a successful positioning in the European and global market, it is necessary for the Netherlands to present itself as one coherent photonics region. This calls for a single agenda and hammock for the photonics initiatives in the Netherlands, reflecting the power of Dutch photonics linked to the application domains. This agenda is the prelude to a number of widely supported initiatives with concrete impact on companies and society.



Demonstration set-up to demonstrate the feasibility of high-capacity data communication between ground station and satellite (TNO)

[17] HTSM Photonics Roadmap, update 2018; https://www.hollandhightech.nl/nationaal/innovatie/roadmaps/photonics

4 / PROMISING CLUSTERS

The Netherlands is successfully working on photonics solutions and the growth of the international market offers many opportunities for Dutch companies. To seize these opportunities more is needed than a few investments in individual development projects.

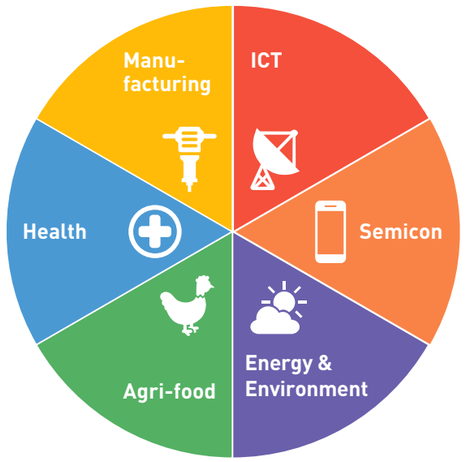
There is a need for far-reaching cooperation in larger clusters of organizations, with broader investment in these clusters. This scaling-up is necessary to put the Netherlands on the map as one coherent photonics region, to successfully compete at a global level, and ultimately to achieve above-average growth in the Dutch photonics ecosystem.

Six promising clusters
For this agenda, we have identified 6 promising clusters, with corresponding application domains. The clusters are aggregated on application domain, and contain companies and knowledge institutes. The 6 clusters are defined as: Health, Manufacturing, ICT[18], Semicon, Energy & Environment and Agri-food (*Figure 4*).

What is a cluster?
A cluster is aimed at an application domain and consists of the value chain and a large number of photonics technologies (*Figure 5*). A cluster is internationally distinctive due to its excellent knowledge institutes and companies and its unique technology position. The cluster has a substantial market size (turnover, number of companies).

FIGURE 4

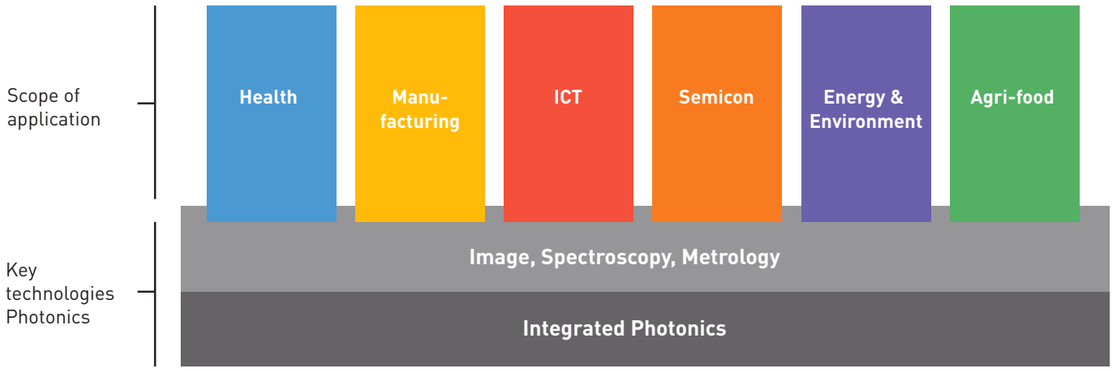
Six promising clusters: Health, Manufacturing, ICT, Semicon, Energy & Environment and Agri-food



[18] In this context, ICT is mainly concerned with the digital data communication domain.

FIGURE 5

The coherence of application areas and key enabling technologies



A cluster is aimed at one or more application domains with the objective of:

- strengthening collaboration between companies in the supply chain;
- valorizing knowledge by means of cooperation between research institutes and companies;
- contributing to societal challenges;
- strengthening the international competitive position of Dutch photonics companies and institutes;
- strengthening photonics education (at vocational and academic levels) and align it with the needs of the market;
- promoting cooperation between key technologies.

Size of the clusters

Out of an estimated 290 photonics companies in the Netherlands, approximately half are active in the development or production of photonics solutions for two or more clusters. For example, a company supplies sensors for the manufacturing industry and for the agri-food sector. *Figure 6* gives an overview of the number of companies active in each cluster.

FIGURE 6

Number of photonics companies in the Netherlands per cluster

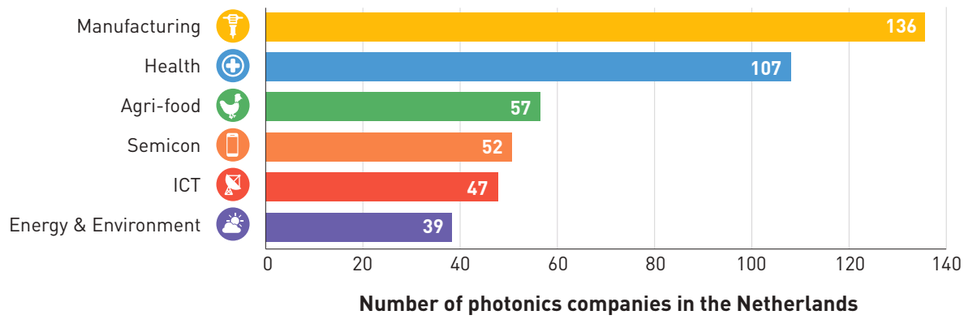
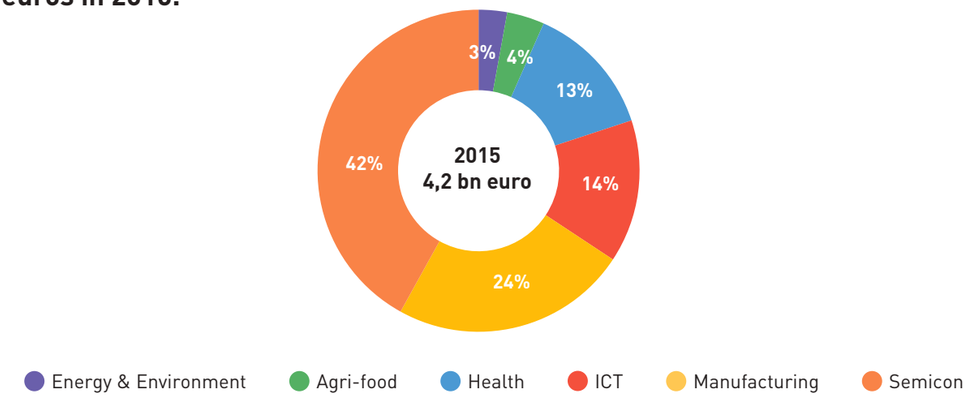


FIGURE 7

Market turnover of clusters in the Netherlands. Total market turnover was 4.2 billion euros in 2015.[19]



Almost half of the players are active in the manufacturing industry cluster. This is a broad cluster. The cluster comprises companies that make displays, lighting, production machines and measuring instruments for the production process (e.g. sensors). The market size for photonics for the manufacturing industry is estimated at 24% of the total market size for photonics. The big actors Signify (Philips Lighting), Océ-Canon and Omron Europe ensure a high level of sales in this cluster.

In addition, 107 companies are involved in photonics for the Health cluster (e.g. medical instruments, sensors or treatment methods). In terms of revenue, this is a relatively large cluster due to Philips Medical, among others. 57 companies are active in the Agri-food cluster. However, its market share is limited: The Netherlands does not have any major players specializing in photonics for agri-food.

There are 52 and 47 companies respectively active in the Semicon and ICT cluster. The Semicon cluster is dominated by ASML, which is responsible for 37% of the total photonics industry in the Netherlands.[19] Many of ASML's suppliers are part of the manufacturing industry cluster.

The fibre-optic companies Prysmian Group (Draka) and Eurofiber are responsible for a high turnover in the ICT cluster. The Energy & Environment cluster is relatively small in terms of number of actors (39) and turnover.

In collaboration with companies and research institutes, the social challenges, value chain and opportunities for the Netherlands were mapped out for each cluster.

[19] Note: For Photonics21, Optech Consulting has estimated the photonics market in the Netherlands at 8.7 billion euros, including ASML's entire turnover. Not all of ASML's activities are focused on photonics. The figures in figure 6 have been adjusted for this. This includes 25% of ASML's turnover as photonics turnover.

4.1 HEALTH

Better care at a lower cost
The need for more and better medical care is increasing with the aging of society and new technological opportunities. Photonics already plays a crucial role in the diagnosis and treatment of almost every major disease - from optical diagnostics to endoscopy and minimally invasive intervention. These and other photonics-based technologies enable us to treat conditions that would have been untreatable two decades ago or for which the treatment had only a small chance of success.

Value chain
The combination of leading university medical centers (UMCs) and a strong scientific position in the field of biomedical photonics gives the Netherlands a strong starting position. Research groups of the university medical centers are well known worldwide and are widely quoted. Universities such as TU Delft, University of Twente and TU Eindhoven have recognized researchers in the field of medical photonics.

Philips Medical Systems is a strong market leader with an organized high-tech supply chain. Several SMEs are also launching photonics instruments into the market, such as Avantes, which supplies spectrometers for the medical sector worldwide. The Netherlands also has a well-organised offerty-box-funds with a specific focus on specific diseases and disorders such as the KWF, the heart foundation, the lung fund and the kidney foundation.

Opportunities for growth for the Health cluster
The Health cluster has growth potential in two themes:

A) Prevention, screening and early detection of diseases
In the future, more and more emphasis will be placed on staying healthy, and on prevention and early diagnosis of diseases in order to reduce the need of expensive treatments and to enable people to participate in society as effectively as possible. This can be achieved, for example, with photonics-based wearables that continuously measure health parameters and provide the user with feedback on their health status and advice on measures to be taken to promote their health.

The demand for non-medical applications and wearables that measure all kinds of health information is growing rapidly worldwide; such solutions can serve as an accelerator for the development of medical wearables.

The knowledge gained in miniaturization, optical design and integration of photonics can also lead to cheaper, more accurate and faster diagnostic methods that can be used in primary health care. In addition, photonics techniques can be used in hospitals for more accurate and cheaper diagnostics based on the unique "optical fingerprint" of disease processes.

App-controlled goggles with integrated LED light helps in applications in classical light therapy, in work at irregular times and on night shifts and, for example, in reducing the effects of jet lag. The innovation in the field of light therapy was developed by Propeaq. These glasses are used, among other things, by Olympic athletes from seven countries, in healthcare, aviation and the service sector.

A great opportunity for Dutch photonics companies is to supply photonics components or products to the industry and end users of these wearables and diagnostic equipment.

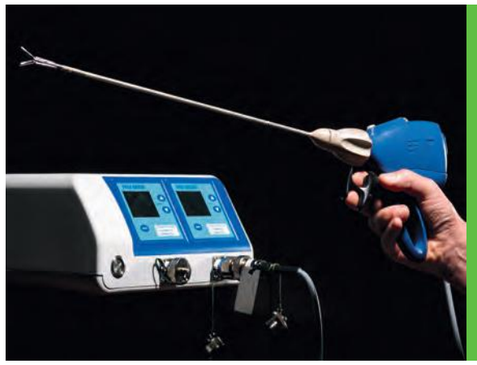
B) Better diagnosis and monitoring for individualized treatment
Not everyone reacts in the same way to a particular treatment. For example, many medicines only work for part of the patients. If this is measured well and at an early stage, costs can be saved by switching to another therapy in good time. Photonic techniques have the potential to measure the effect of interventions more quickly and more sensitively. In addition, image-guided surgery allows borders of anomalies to be made much more visible to the surgeon during surgery, allowing tumors to removed more accurately, resulting in better outcomes and lower costs. Photonic instruments that enable minimally invasive surgical procedures ensure that patients recover faster and spend less time at the hospital.

Monitoring and caring for patients at home provides them with greater living comfort and reduces healthcare costs. A great opportunity for Dutch companies is to develop and supply equipment for better diagnosis, minimally invasive surgery and (real-time) monitoring of therapies. The government can accelerate this type of application by making the market accessible for SMEs, for example by offering financing opportunities to bridge the Valley of Death.

The market for these SMEs will not only be the Netherlands, but also other countries. Promotion of the Netherlands as a strong Medical Photonics cluster is required for this.

Preconditions
Partly because of the method of financing by insurers and the long validation and certification process for medical innovations, it is difficult to obtain sufficient funding for photonics initiatives. And this at a time when there is a great need for close cooperation between all stakeholders, such as patients, medical specialists, scientists and companies, in order to get new instruments and applications onto the market quickly.

These challenges can be addressed through the cooperation within the medical photonics technology centers that are to be established. These will contribute to shortening the technological development time by bringing all stakeholders together. In such a center, scientists, companies and patients work and meet to test and validate the latest photonics equipment and methods for screening, diagnosis, and (minimally invasive) surgery to shorten the time to market. Investments in one or more centers strengthen this innovation, which is important for the Netherlands.



The company EFI launched OptiGrip; OptiGrip is a supplier for minimally invasive surgery that provides haptic feedback to the surgeon through fiber sensors. As a result, the delicate tissues of the intestines are less damaged and the surgeon can operate more accurately and efficiently.

4.2 MANUFACTURING

Digitization of manufacturing
The digitization of the manufacturing industry is one of the central themes for the Netherlands. This transformation is necessary in order to increase productivity, address the growing scarcity of qualified personnel, and promote future economic growth, making industry more sustainable.
Smarter production processes make it possible to use raw materials more efficiently. The transformation to a digital industry requires new production and communication technologies within which photonics plays a major role.

The Creative Industry cluster focuses on the application of photonics in the manufacturing process of products such as electronic devices, displays, machines and cars. The manufacturing industry can be divided into making (production machines and production of photonics systems) and measuring (monitors). Digitization integrates manufacturing with measuring.

Value chain
The Netherlands has 136 photonics companies and (knowledge and education) institutes that are active in the field of the manufacturing industry. Actors in these clusters are active in several markets and application areas.
The technical universities in the Netherlands are pioneers in research into, among other things, laser manufacturing and 3D printing. The companies in this cluster are at the end of the photonics value chain: the customers are often not active in photonics.

The industry consists of producers of optical sensors and spectrometers, as well as machines such as welding machines (e.g. AWL technology) and 3D printers. In fact, producers of semiconductor equipment (including ASML) are also filed under manufacturing. However, due to the size of the semiconductor industry and the differences in applied technologies, this sector is treated as a separate cluster.

With Prysmian Draka, the Netherlands is a global player in the production of glass fibers, which are also widely used in data centers and offices. Philips Photonics also produces VCSELs on a large scale in the Netherlands. VCSELs are compact light sources that are indispensable for interconnectivity in the explosively growing world of data centers.

Major producers of optical components are missing from the Dutch value chain. The optical components (lenses, laser modules, mirrors) in the machines are imported from abroad, the machines are assembled in the Netherlands, and then most of them are exported.

Opportunities for growth in the manufacturing industry cluster

A) 'Smart Industry' applications
The demand for "Smart Industry" applications is increasing in connection with the digitization of industry. The Netherlands distinguishes itself in the high-end segment and in R&D. Large-scale production of sensors and machines, for example, takes place elsewhere at a cheaper hourly rate. On the other hand, flexible, small-scale production (Industry 4.0) offers opportunities for high-quality, flexible photonics solutions that can be developed and produced in the Netherlands.
Integration of photonics solutions within the manufacturing industry requires innovative ideas which can be created at competitive prices. Knowledge gained from the high-grade chip development within the semiconductor industry can be used within the entire manufacturing industry. It is important to have enough production capacity to produce these technologies on a sufficient scale and at competitive prices.

B) Photonic IC production machines
There are opportunities for the Netherlands to develop new optomechatronic equipment for the production, packaging and alignment of photonics devices and microfluidic chips. These are now produced with old lithographic equipment suitable for the semiconductor industry. However, the photonics and microfluidic chip industry requires specific cost-effective solutions for further scaling up of production. In addition, such equipment has become a scarce resource in the semiconductor industry and this is a bottleneck that can be addressed. In the Netherlands, there is an internationally strong optomechatronic chain that can take up this challenge.

C) Strengthening the Dutch manufacturing industry for optical components
The Netherlands has a strong manufacturing industry for high-grade optical components. This photonics manufacturing industry supplies Dutch system builders who integrate these components into even higher-grade (sub-) systems, and is successful in exporting these components because they are of unique quality.

An expansion of this manufacturing industry would expand the Netherlands' leading position (in fiber production, for example), and strengthens both the internal market and exports.

These include, among other things:
- high-quality optical manufacture of mirrors, lenses, glass fibers, etc. (Prysmian Draka, VDL, Sumipro, Diamond Kimberlit, TNO, Te Lintelo Systems, Physix);
- design, assembly and production of light sources (Philips Lighting, ISTEQ, 4PICO);
- development and production of special (industrial) cameras (Adimec, Grassvalley, Amplye).

Series 3D printing with PrintValley (AMSYSTEMS Centre)

Preconditions
A good connection between education, knowledge institutes and the business community is essential for the innovative capacity. Qualified (laser) professionals and mechanical engineers with photonics expertise are desperately needed in the manufacturing industry cluster.
This applies to all levels of education. The exchange of knowledge between knowledge institutes and Dutch companies in the manufacturing industry can also be greatly improved. In addition, pilot sites are needed to accelerate the development process. Sharing facilities and knowledge is central to this.

The National Agenda Photonics aims to improve the link between photonics and existing initiatives. Initiatives such as Platform Techniek in the Northwest region of Belgium encourage students to opt for technical courses.
In the Smart Industry programme, field labs have been created in which the development of skills and the strengthening of public-private partnerships are central. For photonics companies, a many of the field labs are relevant, such as the Dutch Optics Centre, Fieldlab Smart Welding Factory, Frehsteq, Flexible Manufacturing and The Sustainability Factory.

4.3 ICT

Photonics for increasing data flows
The ever-increasing demand for bandwidth and the number of devices and processes that need to be connected implies that existing forms of information exchange will be insufficient within a few years. The development of future multi-terabit communication technologies will be based on optical infrastructure and technology. Technologies needed to address these issues range from laser satellite communications in support of the growing Internet of Things to integrated photonics devices that help increase communication capacity and reduce energy consumption in data centers and consumer communications around the world.

Photonics21: "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."

Value chain
Few large industries are involved in the production of photonics products for ICT in the Netherlands. The field of application of satellite laser communication, for example, is still under development. The first technology development has been implemented through, inter alia, ESA projects at the universities and knowledge institutes, with the participation of the well-known and new Dutch space companies.
In addition, universities and innovative companies collaborate on the development of integrated photonics applications for data centers. This development is driven by an international roadmap, in which scientists and companies from all over the world are involved.
The Netherlands also has a strong position in research into quantum technologies, including quantum encryption, in the Qutech institute. Here, too, there are little or no other commercial parties in the value chain.
Lastly, The Netherlands is host to a rapidly growing company in the domain of fiber-to-home-communications: Genexis.

Opportunities for growth in the ICT cluster

A) Scaling up of satellite laser communications
For satellite laser communication, a leading position (technical and commercial) must be achieved in Europe. In order to achieve this, the Dutch ecosystem will have to concentrate on the efforts of specific high-tech modules. The production has to be scaled up from single pieces to middle-large series, via a strict design-to-cost process.

B) Fast data communication with integrated photonics
Further development of this application of integrated photonics requires the realization of the first generations of products. Based on current research and a number of innovative SMEs with manufacturing facilities, together with an extra emphasis on creating system integrator companies, the ecosystem can grow further and strengthen the international market position. Different material platforms are used in the Netherlands and internationally. It is still open which of these platforms will be used on a large scale in the future. The data centers in the Netherlands are a good local start-market for integrated photonics.

C) Exploring the market for light sources
The market for light sources for telecom UMTS (VCSELs) should be explored, and coordinated technology development is needed to play a role in this. This requires rapid assessment and combining of the knowledge and experience available in the Netherlands. Communication within and between machines, to-home and in-home together form a large application area.

D) Valorizing the knowledge of quantum encryption
For quantum encryption, the strong position in research must be converted into a strong market position; a number of international competitors are active in this respect.

Preconditions
For the ICT cluster, it is important that starting initiatives in the Netherlands are given the proper opportunities to make a product marketable and to sell it internationally.
An example of an opportunity is 'fiber-to-the-home' by Genexis. Wifi and Bluetooth, which were ultimately developed in other countries, are cited as missed opportunities.
The general precondition for the growth of the ICT cluster is that the investment budgets (including venture capital) must be increased. A cooperation between large (knowledge) suppliers and small new parties can increase the success rate of attracting VC capital.

In addition, the relationship with large customers, most of whom are from outside the Netherlands, needs to be strengthened.
This concerns both the large satellite communication companies and the companies that set up data centers and fiber-optic networks. By cooperating with these major players, Dutch industry will be able to capture a larger market share more quickly with new technology.

4.4 SEMICON

Semicon as the basis for digitization
Digitization enables a major transformation of our society in all facets of our existence. The semiconductor industry produces the basic components that enable digitization, such as ASML's chip production machines. Photonics is present in many facets of this production equipment: nano-lithography, lenses, optical sensors, process control, metrology and laser systems. In addition to this branch, there is also the design, production and packaging of ICs, represented in the Business Cluster Semiconductors Netherlands (BCSEMI NL).

Value chain
In recent decades, a globally unique semicon cluster has developed in the Netherlands with companies such as ASML, ASMI, ASM-PT and BESI at its core and an extensive network of suppliers around it. The focal point of this is around Eindhoven, with a broad impact on the rest of the Netherlands and Germany (Zeiss). From a value chain perspective, the focus of the cluster is on manufacturing equipment supplied to companies elsewhere in the world, such as Intel, Samsung, TSMC and assembly houses such as ASE.

Extreme Ultra Violet (EUV) Lighting and Analytical Facility EBL-2 (TNO and USHIO)

Opportunities for growth for the Semicon cluster
Photonics is a broad technological field, with applications in, among other things, metrology and sensors. There is a wide variety of development activities. A greater focus on specific subjects can help to speed up the process. Innovation activities in this cluster focus on a number of main themes:

A) Strengthening and renewing the existing position in semiconductors
Given its unique position, there is now an opportunity to realize the complete development and production of photonics subsystems in semiconductor production machines in the Netherlands. ASML's number 1 position offers the opportunity to bring together more companies in the field of semiconductor photonics. The eco-system of manufacturing companies and 'optical manufacturing around the corner' could be strengthened, as well as the link between design and manufacturing companies. Small businesses can benefit from the image and the position of ASML as a figurehead company.

The unique international position also offers the opportunity to take the initiative for a semicon-photonics roadmap at EU level and worldwide. Research that is placed on the agenda in this roadmap concerns, for example, new light sources and sensor development. The roadmap also helps to implement cooperation with foreign companies/universities and improves the international profile as a leading cluster of Semicon.

B) The utilization of existing knowledge and assets for new applications
The unique technology position in semiconductor photonics also offers ample opportunities to create new products and applications. Application-driven challenges, as a basis for system integration, can give direction to this. For example, lithography machines for printing organic materials and structuring surfaces for the medical industry. The Netherlands is strong in system integration, e.g. through multidisciplinary cooperation with other technologies, whereby the link with manufacturing SMEs needs to be strengthened.

C) Development of new production technology for new types of chips such as PICs
In addition to the development of photonics components for semiconductor production machines, Photonic Integrated Circuits are also on the horizon. These are integrated circuits including light sources. This development is accelerating worldwide[20] with new leading companies taking initiative. A whole new chain (from design and design software to production and production equipment (foundries) is being developed. Further international anchoring of this development is important in addition to the establishment of PITCs (photonics integrated technology centers), as accommodated for in the investment plan of the PPP PhotonDelta.

Preconditions
All of the three main lines described above are enforced by in strengthening the semicon photonics ecosystem. Acceleration can be achieved by bringing together more players (training, business, technology) at regional and national level. PPP cooperation creates room for the development of new innovations and business. This is important because companies have limited access to real innovation due to high pressure from full order books. A strong ecosystem also contributes to attracting new businesses.

4.5 ENERGY & ENVIRONMENT

Photonics for the Energy Transition
We are rapidly consuming fossil fuels. Emissions of gaseous and particulate pollutants from the use of these fuels have harmful effects on the environment and on human health. The consequences of climate change are becoming increasingly clear. And air pollution is one of the greatest threats to public health, according to a report by the World Health Organisation (WHO) published in 2016.[21]

The first step towards limiting this damage was taken at the Climate Summit in Paris at the end of December 2015. The climate ambitions that have been agreed upon must radically change the energy system. Like the other European countries, the Netherlands is faced with the challenge of drastically reducing its energy consumption and CO_2 emissions by 2030.

The technology in this cluster is very diverse. Optical sensors, solar cells and remote sensing contribute to this energy transition. This contribution lies in three areas: decentralized energy generation, large-scale energy storage and climate and environmental monitoring.

Value chain
The Dutch knowledge institutes are well represented in research into solar cells with knowledge institutes such as ECN-TNO, Radboud University Nijmegen, University of Twente, AMOLF and Solliance. The Netherlands makes world-class production equipment, but the production of solar cells hardly takes place in the Netherlands. The larger part of production takes place in China, where production costs are lower due to subsidies and state aid that does not always comply with WTO rules.

The Netherlands also has a lot of knowledge of instrument development for the environment and climate monitoring. Here the Netherlands shows a good track record, also in data processing. However, the value chain is developed to a limited extent.

[20] 600 M$ in the US available for the AIM Photonics Institute for PIC development

[21] WHO (2016). Ambient air pollution: A global assessment of exposure and burden of disease

Opportunities for growth for the Energy & Environment cluster

A) New, cost-effective solar cell solutions
The Netherlands has 892 km² of suitable roof surface for solar panels.[22] By producing smaller, integrated solar panels with high energy efficiency, it is possible to cover the roof surface more effectively with solar panels. This can greatly increase the total energy generation in the Netherlands.

Another chance is to replace asbestos on roofs with solar panels. All asbestos must be removed by 2024. In the Netherlands alone, this is an area of 120-150 million m². This is potentially a large market for solar panels. In addition, sensors can be used to measure the concentration of harmful substances, so that asbestos is removed as safely as possible.

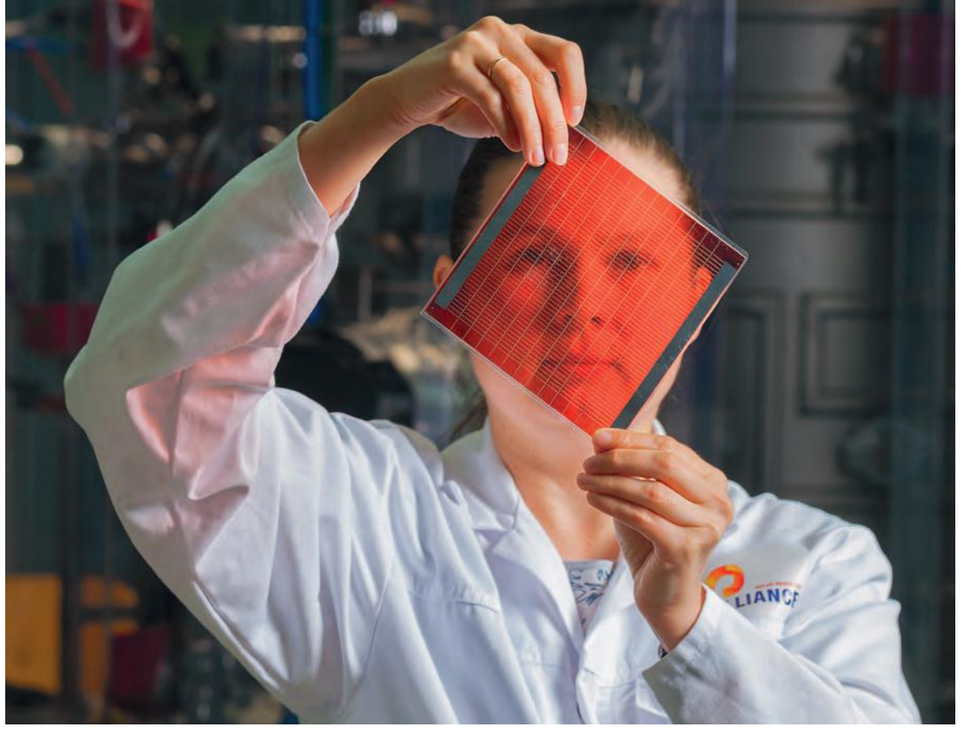
B) Export of air quality meters
Providing instruments for air quality monitoring, or the data, could possibly become a new Dutch export product. There is a large market for air quality meters, for example for governments, insurance companies, households, companies, school boards and hotels. The Netherlands has an excellent technology base for developing these meters. But these opportunities are not yet being seized. Industry and government are barely aware of the opportunities this technology offers for monitoring the environment.

C) Monitoring emission agreements on a State-wide basis
At the Climate Summit in Paris, countries all over the world made agreements on CO_2 reduction and energy consumption. In order to monitor these agreements, the emission of greenhouse gases must be monitored on a statutory scale. This is where opportunities lie for the Netherlands. The Netherlands has a unique technology position in remote sensing from space, which makes it possible to monitor emission agreements at the state level.

Preconditions
The measurement techniques for water and air quality (polluting gases and particulates) are determined by the regulations and, as a result, innovations are not easy to implement. The Netherlands does have the technology to tackle these challenges. This also applies to solar cell technology. Encouraging the government to apply new solar cell technology will be an extra incentive for this type of product. Innovative start-ups are ready to turn new technology into products. The growth of these young companies can be greatly accelerated if they can "grow up" in an incubator environment.

The market is not sufficiently aware of the opportunities offered by photonics. The results of environment and climate monitoring are mainly used for scientific purposes, but hardly for business and consumer purposes. To take advantage of this opportunity, better contact with these end users is necessary, for example via a white paper, which provides insight into the applications of photonics for energy and the environment. In addition, more cross-sectoral cooperation can improve the Dutch competitive position of players in the Energy & Environment cluster, for example codeveloping with ICT to connect smartphone apps to optical sensors for energy savings.

[22] Deloitte (2018) : https://www2.deloitte.com/nl/nl/pages/data-analytics/articles/zonnepanelen.html



Thin foil technique (Solliance)

4.6 AGRI-FOOD

Efficient, sustainable and safe food production
The challenge for the agri-food sector is to feed the growing world's population, which will consist of 10 billion people by 2050. This will require an enormous increase in food production. Agriculture is already responsible for 70% of water consumption, 24% of greenhouse gas emissions and global environmental degradation. Increasing food production with current production processes is therefore unsustainable. At the same time, consumers are placing increasing emphasis on food safety, quality and transparency of the value chain. Increasing concern is also focused on food waste: one-third of all food produced is wasted during production, processing, distribution or at the time of consumption.[23]

Photonics contributes to more efficient, sustainable and safer food production. For example, the Netherlands is developing lighting systems to stimulate the efficient growth of crops and photonics sensors for precision agriculture and food quality monitoring. Specific examples of applications are monitoring soil conditions, monitoring air quality in stalls, predicting the protein content of grain harvests and determining food spoilage with greater accuracy.

Value chain
The strong position of the Dutch agricultural sector is internationally recognized. In combination with the strong knowledge position in photonics at the Wageningen University & Research (WUR) and companies such as Philips Lighting and Unilever, the cluster is well positioned. The agri-food network is accustomed to developing joint R&D. Photonics solutions for the agri-food sector are primarily developed for and with device manufacturers such as Philips Lighting and Lely and their high-tech suppliers such as SDF.

[23] Photonics21 vision paper Europe's age of light (2017)

On the other hand, the agri-food sector is determined by the supply chain. The major food producers, such as Unilever, together with the major retailers, such as AH and Jumbo, have the power over prices and sales. This makes the implementation of innovations in the value chain is difficult.

Opportunities for growth of the Agri-food cluster
The strong, internationally recognized high-tech position of the Netherlands offers the following opportunities:

A) Expanding the position of the Netherlands as a testing ground
The Netherlands is a valuable testing ground for innovations. There are various types of agriculture, external factors are well under control and the land is small and compact. The experimental garden can focus, among other things, on new light systems to stimulate efficient growth, on photosensors for precision agriculture and on sensors for food quality monitoring before and during harvesting, during processing and on the shelf. Acceleration of the living lab can be achieved through efficient innovation financing and the removal of innovation-restricting regulations.

In addition, stimulating cooperation with large international companies and universities, and with countries such as Brazil and China, is necessary in order to position the Netherlands as a high-tech country.

Phenotyping of crops (WUR)

B) New revenue models for the agricultural sector
Development in the areas of the environment, the circular economy and energy transition will lead to opportunities for the Netherlands. For example, the asbestos removal of stabled roofs offers the opportunity to equip the new stabled roofs with solar panels. In this way, the agricultural sector will become a smart power plant. This can be accelerated by a long-term vision, a systematic approach, focus and rapid decision-making and by stimulating cross-over cooperation with the energy domain.
In addition, photonics offers opportunities for new revenue models in, for example, the horticultural sector. Smart use of data exchange systems makes new services such as E-Growing possible. This is a growing-as-a-service concept in which the investor pays for each product produced. The production is controlled by ICT systems that learn from the data generated by the (optical) sensor systems. Acceleration can be achieved by, among other things, focusing on technology development in the field of sensor selection and development and digitalization of crop control.

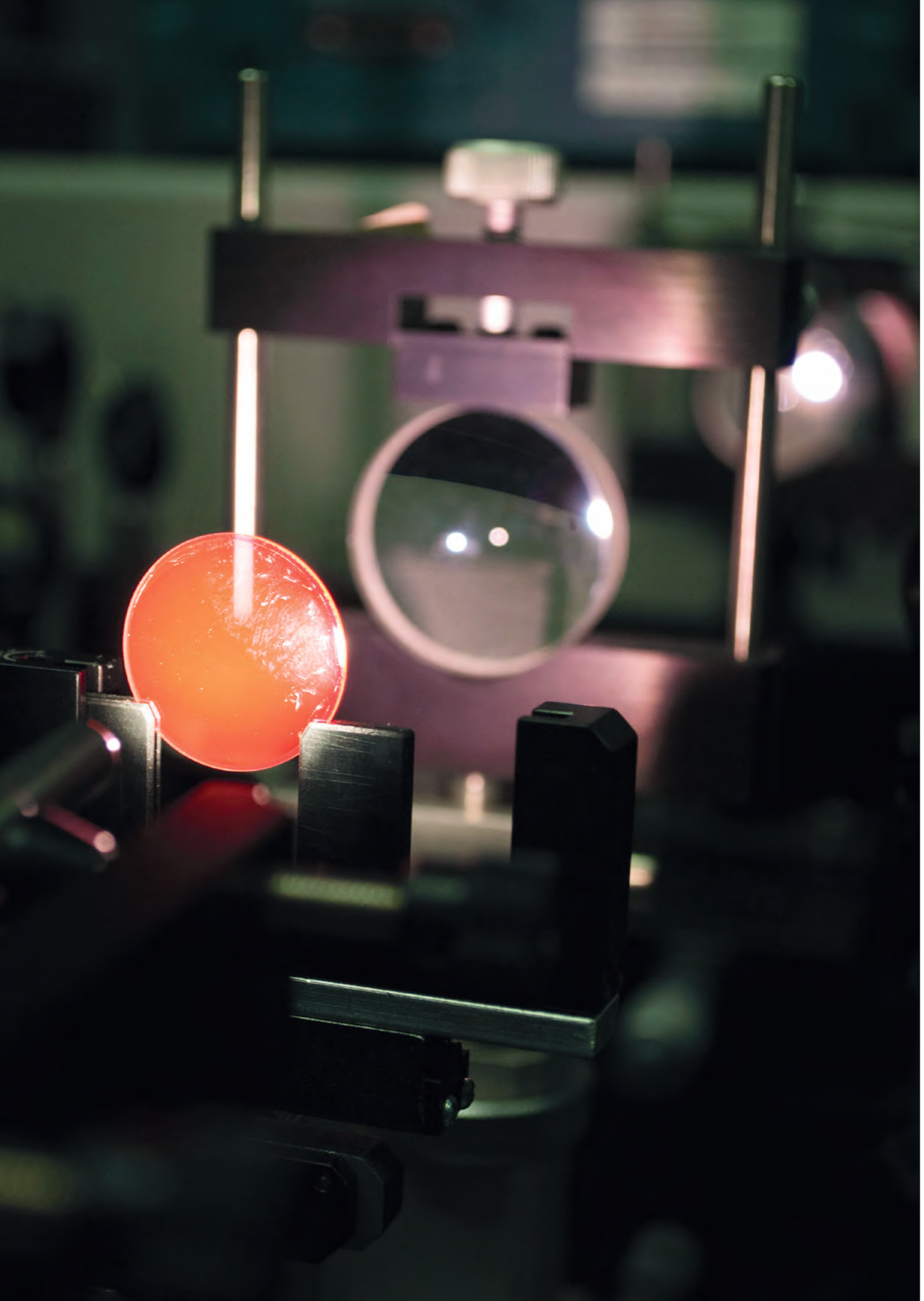
Preconditions
The need for more efficient and sustainable food production processes will accelerate the development of photonics applications for the agri-food sector. New solutions are needed, although potential end users are still reluctant to invest in new technology (partly due to low profit-margins and fluctuating food prices).
In addition, potential end users are often not yet sufficiently aware of the possible solutions that photonics can offer.

4.7 CONCLUSIONS FROM THE CLUSTER SESSIONS

The sessions exhibited in general a consensus on the enormous opportunity photonics offers for the industry. In our knowledge institutes, important innovative technologies are developed and designed, but the instruments for exploiting these opportunities need to be improved.
More and more crossovers are also emerging: links between application areas in which the same technology solution is used.

Important pillars for innovation are the availability of technology, partners, and funding. The technology is widely available: a great deal of unique, useful knowledge is generated at the knowledge institutes. There is still room for improvement in the process of transforming this knowledge into applications for companies quickly and efficiently. The first steps are now being taken to better link the industry to the knowledge roadmaps, and this is proving to be valuable for both parties. The availability of knowledge carriers (specialists in photonics) for companies is still too low; there is a need for more specialized personnel across the full range of application areas, and of both vocational and academic education. At the moment, this limits the growth of the sector. The training of existing staff (skills) and new staff (education) should be intensified. Raising awareness about photonics, and improved branding, is a necessary condition for this.

The first step towards a coordinated approach to these aspects, together with initiatives for investment in joint facilities and enhanced cooperation, is given in the next chapter.



5 / AGENDA FOR THE FUTURE

The previous chapter indicated the points of attention in order to enable the acceleration of photonics development for the clusters. In this chapter concrete proposals are made in the form of awareness- and branding activities, investment plans, knowledge development and education.

The National Agenda Photonics accelerates photonics development in the Netherlands by developing new technology and at the same time making a strong connection with application domains. The vision is that concrete actions and action plans will be initiated by parties that have their roots in key technology photonics and that these will be explicitly anchored in the 6 application domains in the form of clusters.

5.1 AWARENESS AND BRANDING

Awareness

Photonics is an unknown concept among the general public. While this technology is used in many products and is currently undergoing major development. Companies are also often unaware of the opportunities that photonics offers them for product or process innovation. Within the framework of the National Agenda Photonics, new initiatives will be developed to make companies and knowledge institutions aware of the new opportunities and possibilities of photonics. The aim is to create more 'network and link' events and to further intensify innovation scans as they are currently carried out, for example, in the European ACTPHAST[24] programme.

The physical locations created in the framework of the National Agenda Photonics, such as PhotonDelta and the Dutch Optics Centre, could potentially act as a core for strengthening these ecosystems and for broadening the knowledge of photonics among the general public. These centers offer further guidance for questions about the innovation process. For example, questions such as 'what does the market look like?', 'who does what in the Netherlands?' and 'which financing possibilities are there'?

Branding: "Dutch photonics solutions for global challenges".

All clusters indicate that the promotion of Dutch photonics abroad can and should be greatly improved. At the moment there are many different branding initiatives and therefore sometimes the coherence is lacking. Cooperation across initiatives strengthens the position of the Netherlands.

There are also opportunities in cross-sectoral cooperation. The Netherlands is uncluttered and has a compact high-tech ecosystem.

By placing the Netherlands on the world map as a single photonics cluster (with government involvement), the Netherlands will be able to profile itself better to the outside world. The branding of the Holland High Tech group is a good example: the orange house style and characteristic tulip is a well-known concept abroad for 'high tech solutions for global challenges'.

[24] ACTPHAST: "One-stop-shop rapid prototyping incubator" for supporting photonics innovation by European companies. ACTPHAST is financially supported by the European Commission under Horizon2020.

Picture left: Experimental observation of the FRET effect (fluorescence resonance energy transfer; TU Delft)

Actions
The aim is that PhotonicsNL, PhotonDelta, DOC, medical centers and others, in collaboration, are going to intensify the (inter-) national branding of photonics and strengthen the connection with the application areas/clusters by means of concrete communication and awareness-raising initiatives.

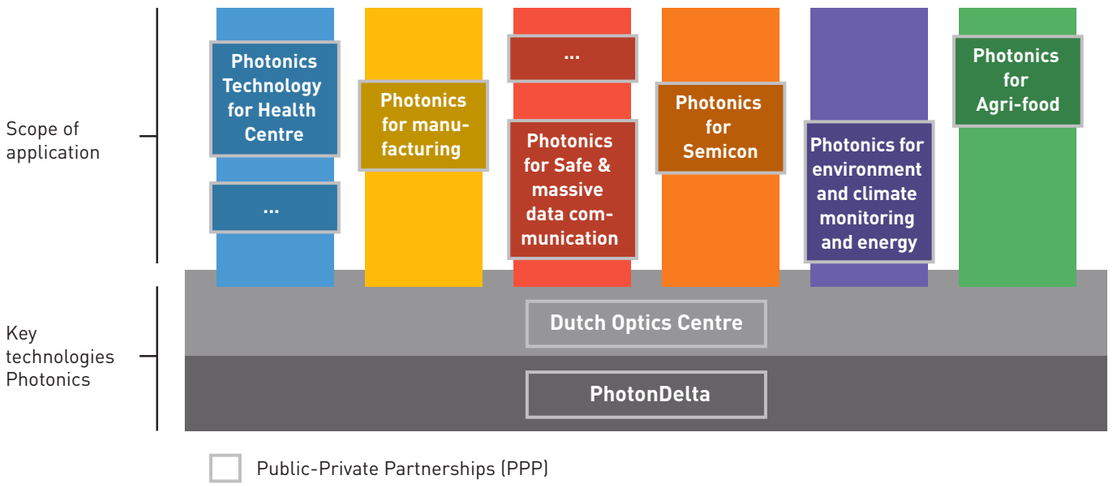
5.2 INVESTMENT INITIATIVES

Various parties in the clusters have joined forces to work together on photonics investment initiatives, usually public-private partnerships (PPPs) for research and innovation (*Figure 8*). These are explained in more detail below. Some of these are well-established initiatives, such as PhotonDelta and the Dutch Optics Centre, while others are new initiatives that were created partly as a result of the cluster sessions for this National Agenda. These investment initiatives fulfill a number of growth ambitions, as described in the previous chapter. It is expected that further initiatives will follow in the coming period.

The starting point for the agenda is that these investment initiatives will focus on new groundbreaking photonics technology development well anchored in the application domains. The PPPs do this through their own programmes. A good connection between the PPPs and the application areas is ensured in at least two ways. The first is to set up and/or strengthen ***application labs***. In this context, parties from the application field and from photonics develop new technological solutions as envisaged in the Medical Technology Centers. Secondly, ***PPP leaders*** are envisioned that are recognized both in the photonics world and in the field of application. These leaders are able to bring together key players on R&D programming and impact assurance. In emphasis, the PPPs PhotonDelta and Dutch Optic Centre are based on their enabling technologies (grey) and the other PPPs on their application domains.

FIGURE 8

Investment initiatives in the context of the National Agenda Photonics



All PPPs take photonics as a starting point and make it applicable. The National Agenda Photonics aims to maximize the synergy effects between the PPPs.

5.2.1 Photonics Technology for Health Centre

Ambition
In the medical field, a strong cluster is present with the ambition to set up the Photonics Technology for Health Centre (PTHC). It translates the latest developments in photonics into the world of life sciences and health through translational research[25]. This is research aimed at developing and translating research results into clinical applications in diagnostics, prevention and therapy. In this way, knowledge is translated at one location into direct applications in the clinic, which can also be performed directly; there is currently a unique colocation of doctors and physicists at the Amsterdam UMC. It is therefore proposed that the focus of the PTHC should also be in this region.

Contents
In the R&D agenda, PTHC focuses on research into and the development of biophotonic solutions and instruments along the entire healthcare continuum. The focus is primarily on neurodegenerative diseases, oncology and regenerative medicine. An extensive elaboration of the R&D agenda is available.

Close relationships between physicists and clinicians are crucial for the joint development, validation, acceptance and application of new medical photonics technologies. In order to achieve this efficiently, special operating rooms are required. As a result, the latest medical photonics techniques, processes and instruments can actually be applied for a direct result.

In addition, PTHC will offer optical lab spaces in and around clinical care for research groups and companies. A translational research programme will be set up to function as a bridge between optics experts and physicians. The PTHC will also guide companies and researchers professionally in the regulation of medical research and the marketing of the accumulated knowledge. An effective route to bringing new technology to the market is through start-ups and scale-ups. In Amsterdam, for example, several successful start-ups in the field of medical photonics have already been produced (Optics11, LUMICKS and Tritos Diagnostics).

Parties involved
The cluster consists of VU, UvA, Amsterdam UMC with connections to the NKI, NIKHEF, the Dutch Optics Centre, PhotonDelta and the recently announced European Medicines Agency (EMA). Other parties involved are:
- The University of Twente, the Biomedical Photonic Imaging Group;
- TU Delft, Medical Instruments & Bio-Inspired Technology Group;
- Erasmus MC, Biomedical Engineering, Center for Optical Diagnostics and Therapy;
- Companies, including LioniX International, FTS, Exometry, Nicolab, Tritos Diagnostics, ScinVivo, Quest Medical Imaging, Avantes, Deam, Heidelberg Engineering (DE), BD Biosciences (USA), Ninepoint (USA), Philips (NL).

[25] Translational research translates results from fundamental research into practical application.

5.2.2 Photonics for manufacturing

Ambition
The ambitions for this application domain are:
- photonics for measuring products and during production, in line with Smart Industry;
- production resources based on photonics technology;
- aspherical and free-form optical components;
- development of front-end and back-end production systems for photonics chips.

Contents
In the manufacturing industry, photonics-based instruments are used for measuring products and making products.

Measuring products during production: Smart Industry
Smart Industry (also referred to as industry 4.0) is an important development in the manufacturing industry; the digitization of the manufacturing industry that increases flexibility and cost-effectiveness.
Advanced optical sensors, 3D-machine-vision and 3D-imaging lay the foundation for highly accurate, uninterrupted production processes and autonomous robots; 3D-vision & vision-in-the-loop systems. Predictive maintenance, made possible by optical observation, monitoring systems and non-destructive test technologies such as infrared, reduces equipment downtime. Rich visual communication such as augmented reality and 3D display technology transform every aspect of the production process, from product design and production to maintenance.

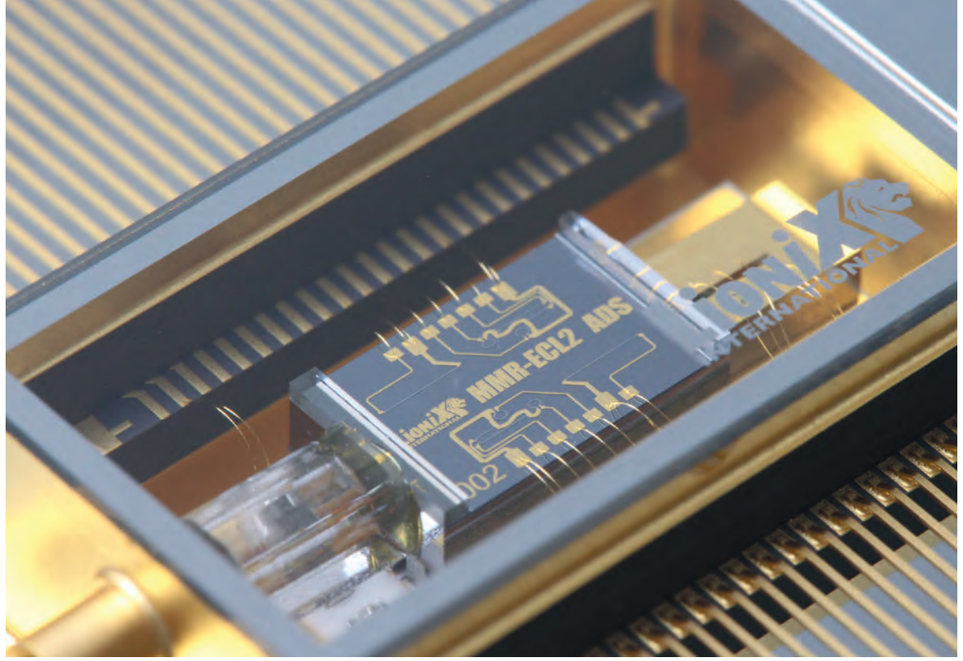
Means of production based on photonics technology
High-output lasers have revolutionized industrial processing and are introducing precision technology, even for small batch sizes. The next generation of laser systems is aimed at faster and more efficient production. The industrial production of micro and nano-materials and -structures is another rapidly evolving spin-off of powerful lasers, which allows nanotechnology applications to be brought from the lab to the market.

Aspherical and free-form optical components
The investment in infrastructure for the production of aspherical and free-form optical components is aimed at strengthening the optical manufacturing industry that supplies and assembles these components. This market is growing at an annual rate of around 10%.
In modern optical systems (from lighting optics and camera lenses to optomechatronic manufacturing and measuring systems), aspherical and free-form optics are becoming the norm.
In the Netherlands, we have unique knowledge (for example at TNO) about aspherical and free-form optics that is ripe for industrialization.

The ***development of front-end and back-end production systems for photonics chips*** offers an opportunity for optomechatronic companies. This equipment is needed for future PIC production. Cooperation between the Manufacturing Industry and Semicon Clusters is important in order to seize this opportunity. This is an overlap between the enabling technologies of DOC and PhotonDelta.

Parties involved
Camera manufacturers (Adimec, Grassvalley, Amplye) and Industrial (vision) inspection systems (EKB, Beltech, SVC, Pliant, ARIS, Vision Partners, DVC). Photonic production tools are developed or used by companies such as ASM-PT, Zenna Lasers, Lightmotif, SOLMATES, TRUMPF NL and Dutch United Instruments. Companies such as VDL, Sumipro, Diamond Kimberlit, TNO, Te Lintelo Systems, Physix are active in the production of free-forms.

In the field of design, engineering & manufacturing of front-end and back-end production systems for photonics chips, VDL, NTS, Hittech, DEMCON | Focal, Dutch Optics Centre, WWINN, Sioux, SsvA, IBS, S&T are already active. Companies such as Micronit, LioniX International, Smart Photonics, Effect Photonics and Technobis are active in the design and production of photonics chips.



Tuneable laser with narrow linewidth (LioniX International)

5.2.3 Photonics for Safe & massive data communication

Ambition
Worldwide, Internet traffic is growing exponentially (eightfold over the period 2015-20120). Secure and broadband connectivity is now a top priority for governments, industries, banks and providers of critical infrastructure. Manufacturers and service providers such as SpaceX, Oneweb, Airbus, Telesat and Thales are working with network operators, investors and governments to create new communication infrastructures with photonics ultra-high transit satellites and huge satellite constellations.
The introduction of a range of new laser communication systems (including Quantum Key Distribution systems) is desirable to enable the next generation of secure and broadband information networks and services. This is an opportunity for Dutch industry.

The aim of this investment initiative is to set up an ecosystem for high-grade serial production of laser communication systems in the Netherlands. Dutch industries, research organizations and universities can build on a very strong position in the development and production of high-quality and reliable photonics systems and terminals for laser satellite communication - and on 40-50 years of experience in the aerospace and semiconductor industries.

Contents
In order to achieve a high-end production series of laser communication systems, a PPP programme is set up. This PPP provides support (facilities and financial resources) for development and production of new laser systems and services in the Netherlands.
The ecosystem, consisting of OEM companies[26] and high-tech suppliers, is open to Dutch companies, institutes and universities. It is supported by Dutch government investors and funds. In addition, this national programme encourages international cooperation.

[26] OEM: Original equipment manufacturer: is a company that produces equipment and parts that may be marketed by another manufacturer.

The focus in this ecosystem is on the Photonics (high power, efficient), Laser/Fiber Techs, Communication/Modulation Tech, Fine & Precise Optics/Opto-Mechatronics (integrated with photonics), High-End Series Photonics Production, and RF-Photonic Transceivers.

The aim of this ecosystem is to secure as many new assignments as possible from manufacturers of communication infrastructure and service providers for Dutch companies. Potentially, this will generate 1 billion euros in the period 2020-2030 through 'high-quality equipment, sales and services', and 2-3 billion euros per year in the coming decade for the provision of the relevant Secure & Broadband Connectivity Services. In total, this means a considerable increase in business activity and high-end workplaces in the Netherlands.

Parties involved
The parties involved are Airbus DS Netherlands, DEMCON, Nedinsco, Hyperion, VDL ETG and Dutch Telecom Service Providers, Cyber Security companies and banks (names cannot be released), NSO, DOC, TNO, Delft University of Technology and Eindhoven University of Technology. In addition, a large number of companies, including many SMEs, have expressed a clear interest in these developments and may participate in the PPP.

5.2.4 Photonics for Semicon

Ambition
The semiconductor industry is driven by Moore's law, which states that the computing power of computers doubles approximately every two years. This is made possible by developments in the entire semiconductor production chain. This production chain can be roughly divided into front-end (including ASML and ASM International) and back-end (including ASM Pacific Technologies and BESI).

Progress is being made in better measurement, imaging and inspection techniques. The Dutch ecosystem is very suitable and very successful in this area. By expanding the Semicon cluster, the Netherlands will continue to make a difference in realizing new photonics developments.

Contents
The R&D agenda for this cluster focuses on four subjects:

Stronger and more versatile light sources
For light sources, attention should be focused on improving the spectrum (i.e. the wavelength of the light) and the brightness of the light source. New metrology and inspection applications require better control of the wavelength of the light source: some applications require a longer wavelength (infrared). Other uses require short wavelengths (ultraviolet or soft X-rays), and sometimes a single color/wavelength of light is required, such as a laser. A second big driver is the intensity of the light. Higher intensity provides a stronger measurement signal and improved measurement accuracy. For laser-driven processes (e.g. cutting or direct imaging), powerful light sources in different wavelengths at low costs are essential for increased production.

Better visualizing optical systems
Optical systems consist of a collection of lenses and mirrors, usually supplemented by more advanced optical elements such as micro-mirrors, optical fibers, holographic elements, grids, prisms, etc. There is a great need for new optical systems that are able to transport, focus and visualize the above-mentioned light. This requires new optical design algorithms and software, and higher optics quality: a smoother optical surface leads to less light scattering and less noise, and free-form optics opens up new possibilities for imaging. For in-process imaging purposes, fast optical systems are needed that also provide resolutions up to 10-100 nanometers.

Developments in detectors
Light detection is driven by measuring speed, high resolution, measuring with more and smaller pixels and a better signal-to-noise ratio. This stimulates various developments in detector and camera technology, such as new detector-materials or spectral-converter-layers on detectors for wider wavelength detection.

Automated image interpretation
Once the light has been detected, the images should be interpreted automatically, and new developments are needed here too. To match with the in-process applications, faster software and processing hardware need to be developed. In order to make all the above developments effective, high-level system integration is required.

Parties involved
The PPP Photonics for Semicon is being taken up by a consortium of organizations such as ASML, DOC, TNO, TU Delft, ARCNL, UvA, UT, VU, DEMCON, VDL, SettelsSavenije, Sioux, VSL.

5.2.5 Photonics for Environmental and Climate Monitoring and Energy

Ambition
The Netherlands has a considerable experience in the development and realization of earth observation instruments (TNO, ADS NL, SRON) and the associated climate science (KNMI, SRON, TNO). The recently launched Dutch TROPOMI instrument with its atmospheric chemistry models is currently considered to be the best in the world. This PPP has the ambition to maintain the position for the Netherlands in the field of instruments and science for climate monitoring and to expand it to the worldwide commercialization of small instruments and related data services. This requires investment in knowledge, technologies and facilities.

Contents
The R&D agenda of this PPP has three areas of attention:

Next generation of imaging instruments
The Netherlands has developed advanced instruments for remote sensing applications using hyper-spectral and multispectral imaging spectrometers for satellite remote sensing in, for example, agriculture and air quality. Next generation instruments will focus on new types of measurements (e.g. infrared, new pollutant gases) and increased accuracy, driven by the needs of industry and industry in areas such as air quality monitoring, biodiversity, agriculture. This will require major progress in the instrument capabilities which will be achieved by the introduction of special optical components, materials, processes and production techniques.

Data usage
The value of Earth observation tools is unlocked by converting them into data products that can be translated in services offered to the government, industries and NGOs, for use in agriculture, air quality monitoring, greenhouse gas monitoring, agriculture and geo-information. This is a rapidly developing market that requires the combination of process knowledge of models, data science ('big data') from universities and institutes, and developments in software and applications that can deliver this to end users on a commercial basis.

Infrastructure
With regard to infrastructure, the aim is to create an easily accessible one-stop-shop for satellites and services. In particular, there is a need for this in commercial space, which is a growing international market. This market is attractive to Dutch industries, for example with regard to small satellite instruments and data products.

This one-stop-shop is a single place where scientists, engineers and technicians come together to develop new design and manufacturing techniques. These collaborations lead to a number of installed spaces for the production, assembly, testing and calibration of instruments that enable the development of prototypes and flight hardware at a single location in one comprehensive process (comparable to the same process).

Parties involved
Airbus, TNO, TU Delft (DOC and DSI), RUL, VU, SRON, ADSNL, Cosine, NSO, Hyperion, ISIS.

5.2.6 Photonics for Agri-food

Ambition
The ambition of the PPP Photonics for Agri-food is to generate impact and develop concrete photonics applications for applications in the entire food chain.
These are applications for:
- sensing for increasing quality during crop growth (from seed to product);
- sensing for the quality grading of products after harvesting;
- food safety sensing in processed products in the rest of the chain;
- new agricultural earning models: urban agriculture, computational farming, algae cultivation in photobioreactors, and solar cells on agricultural roofs.

The PPP focuses on sensor developers, machine builders, agricultural and horticultural end users, researchers, start-ups, spin-offs, knowledge brokers, knowledge institutions, policy makers and investors. To this end, the Netherlands' position as a testing ground for photonics innovations will be expanded by setting up an Agri-food Photonics Hub: a high-tech infrastructure in the agri-food sector.

Contents
The R&D agenda of the PPP focuses on a multitude of technologies: spectroscopy, (high contrast) imaging, multispectral and hyper spectral imaging, photonics system design, high speed/high sensitivity fluorescence sensors in combination with LED lighting, high speed sensors and imaging systems for food quality sorting systems, light-weight quality new sensors for drones and machines in agricultural applications.

The PPP also focuses on exploring new applications of sensors such as terahertz imaging, thermal imaging, microwave imaging, ground penetrating radar, (sun-induced) chlorophyll fluorescence, and LED technology for plant lighting and/or imaging applications.

The hub is both a physical location on the Wageningen University & Research campus and a research platform. Together with the domain experts, technology companies can develop and validate new photonics in the agri-food sector. Activities take place from the hub, such as PPP projects, open calls for photonics issues from industry, innovation experiments/hackathons, testing new technology in agri-food applications, working on standards for sensors in automation systems (cloud), summer schools and customized training courses.

The hub can also serve as a testing ground for revolutionary crossover innovations, in which, for example, local agriculture is combined with personalized diets for nutritional medicine. For this purpose, a laboratory facility can be built in the northeast of the Netherlands for development, assembly, project types and pre-industrial test systems.

Parties involved
4TU, Wageningen Research, Rikilt, DOC, TNO, TU Delft, Ocean Optics, Avantes, Fluxology, Spectra Partners, Cosine, DVC, Stemmer, Teledyne Dalsa, University of Twente, Weijland, with possible participation of Meyer-Burger, Fraunhofer-ISE & ECN, Zernike Institute RUG, HyET, Beyer and DSM.

Optimization of crop lighting (WUR)

5.2.7 Dutch Optics Centre

Ambition
The Dutch Optics Centre (DOC) is a consortium of knowledge institutes and more than 150 high-tech companies from all over the Netherlands. The initiative of TNO and Delft University of Technology is realized through collaboration in application-oriented R&D and the formation of product consortia, a strong Dutch photonics ecosystem. DOC develops enabling photonics technologies for all kinds of market applications. Additional emphasis is placed on the technology platforms metrology, spectroscopy and imaging. Depending on the application, these are supplemented by optomechatronics and other optical technologies.
The broad field of work requires R&D competencies and facilities in a broad wavelength area: from x-rays for lithography for the production of ICs, to infrared for spectroscopy for diagnosis via breath analysis and for monitoring crops.

Contents
Key drivers of research and development are extreme demands for resolution, sensitivity and speed, combined with miniaturization and cost reduction. Unique new instrument concepts are made possible by the application of new techniques and components. An application for a broad research programme called Synoptics for the TTW Perspective programme is currently underway, with enthusiastic support from the industry.

Optical metrology is essential for monitoring industrial production processes. For the manufacturing industry, 100% error-free production is required within the framework of Smart Industry. Underlying technologies are (white light) interferometry for measuring shape and deformation, 3D imaging for inspection, phase sensitive detection and fiber sensors.

Load-bearing structure for mirror segments for the European Extreme Large Telescope (E-ELLUS; VDL, TNO, NOVA, ESO)

Spectroscopy investigates the composition of materials and living matter, for example, measurements of greenhouse gases from space and spectroscopic images of the skin for the detection of cancer. Technologies: multispectral imaging, Raman spectroscopy for the recognition of molecular structures, LIBS spectroscopy for the identification of chemical elements and high-precision spectroscopy based on frequency combs.

Imaging is a widely used technology. In computational imaging techniques such as ptychography, the object is reconstructed from multiple intensity measurements of light scattered throughout the object, without the use of lenses, and with greater depth of field. These technology platforms are essential for large companies such as ASML and Philips (Lighting), as well as for SMEs. In order to achieve intensive cooperation and give companies access to new technology, shared facilities are needed, with high-quality labs and clean rooms. Recently, a proposal for such a facility, called LINX, has been accepted. Future facilities may include components such as a coherent soft x-ray source for wafer metrology made with EUV light, new frequency comb lasers and quantum cascade lasers for high-resolution medical imaging, near-field optics for high-resolution imaging and metrology, and free-form optics production facility.
Based on the needs of the industry, the capacity of existing unique facilities must be increased. Specialised technicians are needed for the support/operation of the facilities. Network meetings and courses will be organized, and an optical specialization in the master's study will be organized, in collaboration with Jena University and the Dutch and German industry (ASML, Philips, Carl Zeiss).

DOC will play an active and coordinating role in the six application-oriented investment initiatives and will play a bridging role in this respect, for example in the crossover of technology between different application areas and facility sharing.

Parties involved
The parties involved are more than 150 national, as well as international knowledge institutes, companies, governments and investors.

5.2.8 PhotonDelta

Ambition
The ambition of the PPP PhotonDelta is to make the Netherlands the world leader in the field of integrated photonics. Integrated photonics is an enabling technology for many applications that, due to their scale, cost and size, want to bring different photonics functions into a single chip. In the field of integrated photonics, the Netherlands has a unique knowledge advantage that offers many economic opportunities. To make the most of these opportunities, it is of great importance that governments, industry and research institutions work intensively together by investing in the development of technology and young chain parties in PhotonDelta, the national industrially driven integrated photonics system.

Contents
The R&D programme and roadmaps of the PPP PhotonDelta focus on the next generation technology, materials, circuits and systems needed to develop new applications. In addition, specific programmes are needed to make the equipment in the chain, from design to production to assembly, suitable for scalable production.
The investment plan identifies specific actions and investments in four pillars:
- Pillar 1: in the value chain, every two years, as complete and professional as to be able to deploy a national platform;
- Pillar 2: in industry-driven R&D programmes and roadmaps to create the next generation of technology, systems and circuits;
- Pillar 3: in infrastructure and expertise to facilitate industry-driven programmes;
- Pillar 4: expand the ecosystem with new start-ups and within existing businesses through intensive collaboration with companies and institutions that have access to the promising areas where integrated photonics will be used. This also offers opportunities for the valorization of new knowledge. It is particularly in this pillar where the significance of the National Agenda Photonics for PhotonDelta cannot be underestimated.

Parties involved

Equipment
Parties from the equipment industry and manufacturing companies, including Aixtron, DEMCON, SmartPhotonics, PhiX, ASML, Ficontech and Boschman.

Applications
Parties that offer solutions in specific markets, including Prodrive Technologies (automotive), EffectPhotonics, LioniX International (data/telecom), Technobis (AeroNautics), Microsoft (data centers), Cisco, Nokia (telecom), PhotonX, Genexis, Vtec, Signify.

Research
TU Eindhoven, University of Twente, Delft University of Technology, TNO, Radboud University Nijmegen.

5.2.9 Actions to ensure the success of investment initiatives

In order to make the investment initiatives a success, the following actions are foreseen.

Actions
- Existing initiatives in the field of photonics will be involved in the implementation of the National Agenda Photonics.
- New PPP initiatives, including the investment initiatives described above, will be developed before October 2018.
- Where possible and useful, application labs will be set up or established to promote physical collaboration between photonics experts and application domains.

Who
Leaders of PPP initiatives

5.3 KNOWLEDGE ROADMAPS

The development of knowledge in the field of photonics in the Netherlands is supported by a wide range of companies and knowledge institutes as described in chapter 3. The most relevant Dutch knowledge agendas for photonics are Knowledge and Innovation Agendas (KIAs), Top Sectors Roadmaps and the National Science Agenda (In Dutch: NWA). These agendas link sectoral agendas of the top sectors, departmental agendas, the National Science Agenda and Horizon 2020 and anyone interested in science.

Within the framework of this National Agenda Photonics, efforts are being made to improve the connection between the Photonics Roadmap - update 2018, and other roadmaps. Attention will be focused on the application areas (medical, agri-food, semiconductor, etc.). The objective is that the PPP initiatives identify and develop projects for photonics development in the application areas, projects that bridge the gap between the photonics roadmap and an application-oriented roadmap. An example of this is Photonics for Smart Industry, which is reflected in both the 2018 Smart Industry Roadmap and the 2018 Photonics Roadmap.

Action
The PPP initiatives (among others from section 5.2) will identify and develop concrete R&D projects for photonics development in the application areas, in order to strengthen the valorization of photonics.

Who
Leaders of PPP initiatives

Action
Photonics IPP subsidy: a special call for proposals is proposed, focused on photonics to strengthen cooperation between universities, knowledge institutes and the business community. Special attention should be paid to partnerships with SMEs (reduction of SMEs' monetary contribution).

Who
NWO

5.4 SKILLS AND EDUCATION

Dutch companies and institutes are known for their high level of knowledge. In many of the Dutch photonics companies more than half of the employees work in R&D. The clusters indicate that there is a scarcity of well qualified is staff.

In order to solve this scarcity, improve transfer and application and keep employment here, three main lines of action are important:

A) Better education
Basic knowledge about classical optics must be included in the standard training package of engineers and scientists - this shortens the training time. By investing in better education and training (MBO, HBO and WO), the level of knowledge will also be safeguarded in the future. Finally, the photonics and optics training courses can be strengthened with, for example, business schools for the semiconductor, nano, bio and space photo-photonics domain.

B) Attracting staff
The Netherlands has an attractive living climate. It is well known that students often stay in their student cities for this reason. This attractive climate can be used to attract new staff. Aside from that, a photonics incubator can attract extra international students. Finally, photonics must be made known outside the photonics market in order to attract staff from other sectors.

C) Exchange of knowledge between companies and institutes
The exchange of knowledge between knowledge institutes and Dutch companies must be strengthened. This can be done, for example, by 'exchanging schemes with universities/companies and guest lectures', but also by stimulating long-term cooperation between companies and knowledge institutes in (research) projects. This will enable knowledge that has been and is being developed at the knowledge institutes to flow to the companies. This can be stimulated, for example, by a subsidy call for research projects on photonics, but also by subsidies to allow existing fundamental photonics knowledge to be landed/applied in companies. By stimulating long-term cooperation, stable and continuous knowledge exchange can be achieved.

Action
PhotonicsNL will contribute to the awareness campaign for 'working in photonics'.

Who
PhotonicsNL

Action
PPP initiatives will set up skills-related actions in collaboration with HTSM's Human Capital Agenda.
This can be done, for example, by setting up teaching modules or skills-labs linked to the above application labs photonics. This will also strengthen the exchange of knowledge between companies and institutes.

Who
PPP initiatives

Action
The aim will be to strengthen the cooperation and connection between education and the knowledge required by the market. For example, by introducing a three-month internship for PhD's at one of the Dutch companies in order to prepare future scientists and engineers for working in a company.

Who
NWO

6 / PRECONDITIONS

The objective of the National Agenda Photonics is to intensify and accelerate the application of photonics technologies for solving societal challenges and creating new businesses.
In the previous chapters we have seen that there are obvious opportunities for the Netherlands in the fast-growing market of photonics in which the Netherlands is strongly positioned.

Photonics innovations can form a crucial asset in the future economic and social renewal of the Netherlands. For a successful positioning in the European and global market, it is necessary to position the Netherlands as one coherent photonics region. This requires a single agenda, a stepping stone for the photonics initiatives in the Netherlands. By focusing on clusters, in which new photonics development is linked to concrete application domains, this cohesion can be realized and the field can be accelerated in a targeted manner. Substantial and leading initiatives have already been launched and new consortiums are on the starting blocks to realize this agenda.
This chapter describes the organizational and financial preconditions that must be met in order to realize this agenda.

6.1 ORGANIZATION

The National Agenda Photonics sets in motion a long-term movement. We are setting our sights on an eight-year programme. As far as possible, existing structures and organizations will be connected and used. Photonics already has an existing roadmap within the top sector HTSM and it will align itself with the Human Capital Agenda.

PhotonicsNL, the Dutch network of all companies and knowledge institutes active in the field of photonics, is well positioned to further shape the networking activities of this agenda.

In particular:
- communication and awareness, where possible in cooperation with other networks in the Netherlands and Europe;
- Supporting PPP leaders to strengthen their links with application areas and societal challenges, as well as with other top sectors.

PPP initiatives and application centers:
- operate independently and are responsible for their own results and implementation;
- contribute to the implementation of the agenda with regard to awareness, R&D, development projects, knowledge and skills.

In the coming months, a joint approach to making the National Agenda for Photonics a success will be further developed in consultation with the parties involved.

6.2 FINANCE

Funding
The implementation of this agenda starts with the commitment and initiative of the clusters and the knowledge institutions and companies working together in them. The photonics clusters in this agenda will count on the support of national, regional and international governments, using various financial instruments, including national, regional and European resources.

Picture left: Basic Angle Measurement System to determine the stability of the space telescopes of the GAIA mission (ESA)

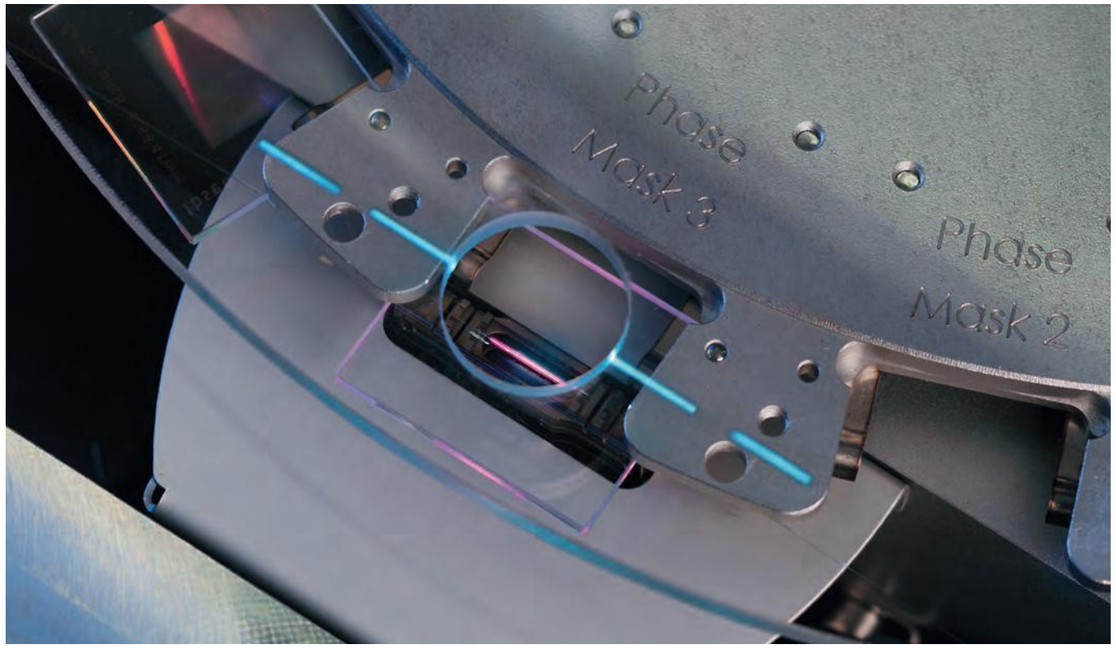
For the new investment initiatives within the framework of the National Agenda Photonics - in addition to the now formulated programme of the PPP PhotonDelta - an investment amount of around 30 million euros per year is foreseen, including 5 million euros per year in private investments. An initial budget estimate will be drawn up for the various public-private partnership initiatives in these clusters.
In the case of PPP research projects in which a TU or a TO2 institute is involved, an application will be made for the PPP rule, whereby 30% subsidy is possible on the basis of the private cash contribution.

The PPP initiatives will explore, in dialogue with the TO2 institutions, the possibilities of programming funds from the Envelope region to strengthen applied research.

The PPP initiatives will join the "Region Deals" by October 2018.

For large PPP initiatives, attempts will be made to reach long-term agreements with financing partners such as RVO and InvestNL in order to deploy the full range of subsidy and financing instruments across the entire research, development and market introduction chain. These include the Innovation Loan, the SBIR scheme, the Seed Capital Scheme and the Guarantee Scheme for SME Loans (BMKB).

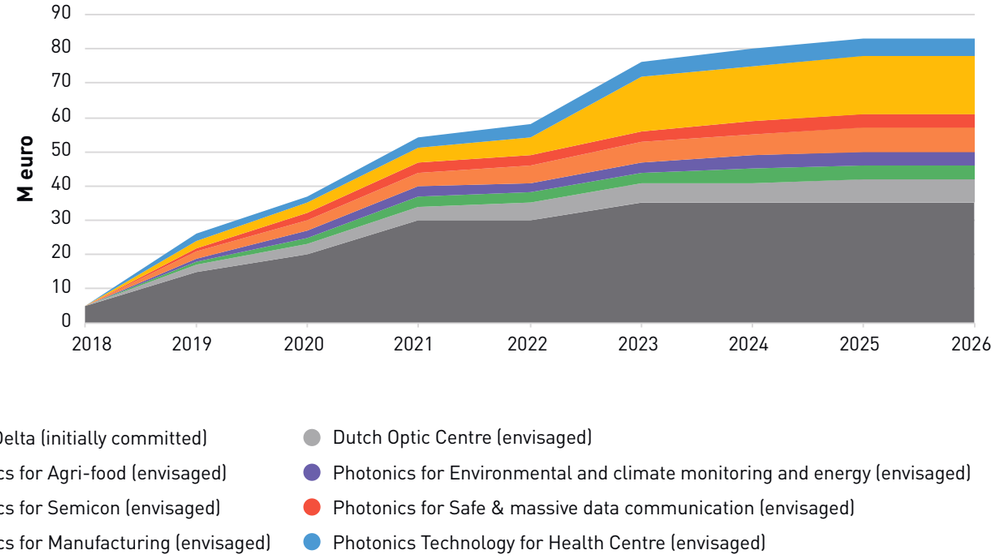
Although there are no specific NWA routes dedicated to photonics (see 3.4), the routes Energy Transition, 'Sustainable production of healthy and safe food', 'Healthcare research, prevention and treatment', 'Personalised medicine: starting from the individual' and 'Smart Industry' provide clear starting points for cooperation with the photonics clusters Energy, Agri-food, Health and Manufacturing. The NWO calls for these routes will be closely monitored.



Laser system for roasting sensors in fiberglass (SOMNI)

FIGURE 9

Global financing National Agenda Photonics, initially committed and intended



The INTERREG programme will be actively used for cross-border cooperation initiatives within the EU. Calls from Horizon2020 and the next Horizon Europe Framework Programme, in which photonics has been repositioned as key enabling technology, will also offer funding opportunities.

For the investment initiatives in the context of the National Agenda Photonics, a need of in the order of 60 million in investment per year is forecasted, to be financed partly by the public and partly by the private sector (*Figure 9*). This is to strengthen the hundreds of millions of euros already invested by the market in photonics.

7 / ANNEXES

7.1 LIST OF PEOPLE AND ORGANIZATIONS INVOLVED IN THE DEVELOPMENT OF THE AGENDA

Steering Committee
Arnold Stokking (chair of steering committee; TNO/DOC), Luuk Klomp (EZK),
Benno Oderkerk (PhotonicsNL), René Penning de Vries (PhotonDelta).

Core team
Erik Ham (DOC/TNO), Bart Snijders (DOC/TNO), Ruud Baartmans (TNO), Babette Bakker (TNO),
Tom van der Horst (TNO), Ron van der Kolk (PhotonicsNL), Anke Peters (DOC/TU Delft),
Bernd Rietberg (TNO), Maarten van Reijzen (TNO), Richard Roemers (EZK),
Ewit Roos (PhotonDelta), Eddy Skipper (RVO), Maria Sovago (NWO).

Experts involved
Arjen Amelink (TNO), Luc Augustin (SMART Photonics), Edwin Beckers (DEMCON),
Johannes de Boer (VU University), Jan Boers (Dino-Lite digital microscopes),
Joline Brouwer (OostNL), Maurits Butter (TNO), Gerard Cornet (SRON), Andy Court (TNO),
Klaas Jan Damstra (Grassvalley), Paul van Dijk (LioniX International),
Gerard van den Eijkel (DEMCON), Hein Otto Folkerts (ASML),
Sonia M. García-Blanco (MESA+, University of Twente), Ludo Geraets (Nedinsco B.V.),
Steven Goetstouwers (Admesy B.V.), Roger Groves (TU Delft), Marc Hak (Dino-Lite Europe),
Frans Harren (Radboud University), Marinus van der Hoek (VanderHoekPhotonics),
Mark Jacobs (Optics11), Sytze Kampen (ADSNL), Ton Koonen (TU Eindhoven), Dick Koster (NWO),
Eric de Leeuw (Diamond Kimberlit B.V.), Zhaohan Liu (VTEC Lasers & Sensors),
Ben Lubberman (SUMIPRO b.v.), Hans Michels (Sioux Group B.V.), Jan Mink (VTEC Lasers & Sensors),
Ramon Navarro (ASTRON), Remco Nieuwland (Somni Corporation B.V.),
Benno Oderkerk (CEO Avantes and chairman of the board of PhotonicsNL), Michiel Oderwald (TNO),
Barry Peet (BCSEMI NL), Callie Peters (Weijland Technologies B.V.),
Marc Peters (Solar Application Lab B.V. and Weijland Technologies B.V.), Paul Peters (Fluxology),
Gerrit Polder (Wageningen University & Research), Oded Raz (TU Delft),
Gert-willem Römer (University of Twente), Eddy Schipper (RVO), Meint Smit (TU Eindhoven),
Maria Sovago (NWO), Marcel Tichem (TU Delft), Niel Truyens (TNO), Paul Urbach (DOC/TU Delft),
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Colophon
Design: Raymakers Ontwerp, Inge Raymakers
Press: Peters Publiciteit, Jos Peters
Photography: Fresh Images (cover), Fred Kamphues (p2), Casper van ´t Hoff (p7),
Bart van Overbeeke Photography (p10), Ivar Pel Photography (p16),
Lamberts Instruments, Avantes (p17), Philips, TNO, Tocano (p18), D.J. IJlst (p22), Propeaq (p26),
Eric de Vries (p27), Bart van Overbeeke Photography (p29), TNO (p32), TNO (p35),
Wageningen University & Research (p36), TU Delft (p37), LioniX International (p43),
Wageningen University & Research (p46), TNO (p48), Fred Kamphues (p52), Arjan Brand (p54).

PhotonDelta
Integrated Photonics Ecosystem

PhotonicsNL
NETHERLANDS

Dutch Optics Centre
a TNO and TU Delft initiative