2024

# Finnish National Photonics Roadmap

2025 - 2030

PHOTONICS FINLAND

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# List of Acronyms

aalto – Aalto University
AER – Assembly of European Regions
AI – Artificial Intelligence
CT – Computed Tomography
EBN – European Business Network
EEN – Enterprise Europe Network
EICs – Electronic Integrated Circuits
EOS – European Optical Society
EPIC – European Photonics Industry Consortium
ERRIN – European Regions Research and Innovation Network
FiCCC – Finnish Semiconductor Competence Center
FOS – Finnish Optical Society
helsinki – University of Helsinki
iDEEP – Doctoral Education Ecosystem for Photonics
iPSRS – Intelligent Photonics for Security Reliability Sustainability and Safety
IoT – Internet of Things
JYU – University of Jyväskylä
LED – Light Emitting Diode
MEMS - Microelectromechanical systems
MRI – Magnetic Resonance Imaging
MRL – Manufacturing Readiness Level
MTP – Micro-Transfer-Printing
OLED – Organic Light Emitting Diode
oulu – University of Oulu
PF – Photonics Finland
PICs – Photonic Integrated Circuits
PREIN - Flagship for Photonics Research and Innovation
QKD – Quantum Key Distribution
SMEs – Small- to Medium-size enterprises
SoC – System-on-Chip
TAU – Tampere University
TFLN – Thin-Film Lithium Niobate
TRL – Technology Readiness Level
UEF – University of Eastern Finland
UTU – University of Turku
VTT – VTT Technical Research Centre of Finland

# Introduction

## Photonics: A key technology to drive innovation and economic growth

Photonics, the science of light, is at the forefront of technological innovation, driving advancements in numerous sectors. Photonics has a privileged status within the EU as one of six key-enabling technologies[1]. Photonics is not only recognized within the European Commission[2] and EU Member States as a "key enabling technology", but one with the potential to underpin a stronger more resilient European economy. This is equally the view of Europe's scientific leadership, as three Nobel Laureates stated to the European Commission "there can be no European digital sovereignty, no secure European digital infrastructure or no secure European quantum communications without a European photonics capability and capacity"[3]. In short, Photonics is essential to tackling challenges in existing and emerging sectors. Photonics has been identified as a key area in Finland's **Semiconductor Industry Roadmap**[4], highlighting its potential to drive innovation and economic growth. Photonics-driven innovation further plays a critical role in creating sustainable and technologically advanced solutions for example, in quantum technology, high-performance computing, and XR technologies.

## Objective of this roadmap

This document proposes a vision and pathway forward for Finnish Photonics. It represents a short to medium-term strategy for the period 2025–2030 and action recommendations designed to realize the full potential of Finnish Photonics. It ensures that Finland strengthens its role as a European leader in photonics and translates innovation into economic success.

Chapter 1 elaborates on terminology related to the field of Photonics clarifying the importance of Photonics. It highlights its capacity for innovation and positions it as key technology to enable growth.

Chapter 2 provides insight into the Finnish Photonics Ecosystem by overviewing the industry, research, education and market. The Photonics Industry in Finland is growing steadily and its doubling is projected by 2030. Photonics research in Finland is at the forefront of technological innovation covering all current topics in photonics, material development, and quantum technologies. It is driven by world-class universities and research institutes. Educational activities in Photonics are present at university level, at applied university, and also vocational studies level. Furthermore, adult education and workforce upskilling courses are available too. The Finnish photonics market encompasses several key segments, including industrial manufacturing, healthcare, and telecommunications. Emerging segments such as quantum photonics and biophotonics offer significant opportunities for future growth and innovation.

Chapter 3 presents how photonics provides the means to address the world's most pressing challenges from climate change and energy efficiency to healthcare, security, dual-use applications, and digital transformation.

Chapter 4 provides an overview of how the Finnish Photonics community and its national association, Photonics Finland[5], has grown from an academic-centered society established in 1996 to a company driven triple helix bronze labeled ecosystem in 2024.

Chapter 5 elaborates on the mission to double the Finnish Photonics by 2030 and the vision which guides that growth.

Chapter 6 builds on Chapter 5 by listing specific actions that need to be executed for the mission to be reached. It highlights funding needs, infrastructure development needs, collaboration, networking, support for business growth and commercialization of innovations, education and training development.

Chapter 7 highlights principles for further ecosystem growth. This growth is essential for reaching previously set goals and provides the foundation for executing the actions recommended in Chapter 6.

1. https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/key-enabling-technologies_en
2. European Commission, COM (2020) 102 final, "A new industrial strategic for Europe"
3. Letter from three Nobel Laureates, Gérard Mourou, Stefan Hell and Theodor Hänsch to European Commissioners Gabriel and Oettinger stating "Photonics is simply essential for powering the European digital economy", published on 28 October 2020 at https://www.photonics21.org/2020/ nobel-laureates-warn-jobs-economic-growth-and-lifesaving-healthcare-at-risk-due-to-proposed-ec-sci
4. https://teknologiateollisuus.fi/wp-content/uploads/2024/09/Chips-from-the-North-Semiconductor-Strategy-for-Finland.pdf
5. www.photonics.fi

# Why Photonics?

The significance of photonics is evident in its diverse applications. From industrial production and manufacturing to health, security, metrology, and sensors the presence of photonics inevitable. Photonics technologies fulfill basic needs in everyday life and are integral to almost all sectors of industry. This includes the development of photonic systems, instruments, and components that are crucial for various industrial applications. By leveraging the unique properties of light, photonics technologies enable advancements in areas such as telecommunications, medical devices, and environmental monitoring.

Photonics technologies are used in many everyday devices and systems. They are integral to smartphones, which utilize photonics for cameras and displays. High-speed internet relies on photonics for data transmission utilizing fiber-optic cables. In healthcare, photonics technologies are used in diagnostic tools such as MRI and CT scanners, as well as in various laser-based surgical instruments. Even in entertainment, photonics plays a role in the development of high-definition televisions and virtual reality headsets.

Since 2012 photonics components industry has grown at a rate of more than twice (2x) global GDP over the same period. Global annual revenues from production of optics and photonics core components reached $368 billion in 2022[4]. Since 2020 the growth is 26 and well above global GDP growth of 18 percent. Production of optics and photonics core components spans at least 52 countries. 4,706 manufacturing companies produced core photonics components in 2022, 84 percent of which are small- to medium-size enterprises (SMEs). Core components production employs more than 1.25 million people worldwide. The global share of the photonics components business has shifted during the past 10 years, with increased dominance of companies headquartered in China, Korea, and Taiwan. Japan-headquartered companies in 2022 generated the most revenue and employed the largest number of people in the photonics components manufacturing industry. The global photonics market size accounted for $982.51 billion in 2024, grew to $1048.64 billion in 2025 and is predicted to surpass around $1884.53 billion by 2034, representing a healthy CAGR of 6.73% between 2024 and 2034[5].

The economic impact of photonics in Finland is profound. In 2023[2] the Finnish photonics industry marked a remarkable growth. Since 2020[1] the overall growth has reached over 50%. The industry's total annual revenue is estimated to be over €2 billion, with more than 300 companies actively engaging in photonics activities. The number of companies in the photonics sector has risen significantly, directly employing over 6,000 people and indirectly providing jobs for more than 40,000. These companies, primarily small enterprises with an annual turnover of less than €5 million, contribute significantly to the local economy. Additionally, Finnish photonics companies are highly export-intensive, with key markets including Europe, the USA, and Asia. Approximately 36% of these companies generate their revenue almost entirely from exports.

Photonics is also a critical component of the innovation ecosystem. In Finland, the Flagship for Photonics Research and Innovation[3] (PREIN) has been instrumental in advancing photonics research and fostering collaboration between academia and industry. Such initiatives highlight the role of photonics in driving forward-looking solutions to societal challenges and promoting economic growth through new business opportunities.

The potential of photonics is vast and continually expanding. Finnish photonics companies have high growth expectations for the next three years, projecting an annual turnover growth rate of 31%, market size growth of 26%, and an 18% increase in the number of employees.

**Key Points:**

- Photonics drives advancements in industrial production, healthcare, security, and environmental monitoring.
- In 2023 the Finnish Photonics Industry records an 18% annual growth in turnover.

1. https://www.photonics.fi/beta/wp-content/uploads/2021/10/Photonics-Industry-in-Finland-2020-Spring.pdf
2. https://www.photonics.fi/wp-content/uploads/2023/06/Photonics-Industry-in-Finland-2023.pdf
3. www.prein.fi
4. https://spie.org/community-support/industry-resources/global-industry-report
5. https://www.precedenceresearch.com/photonics-market

- In 2023 the Finnish Photonics sector directly employs over 6,000 people and indirectly over 40,000.
- Initiatives like PREIN foster collaboration between academia and industry, promoting economic growth and innovation.

# Photonics in Finland – Strengths and Opportunities

This chapter elaborates on the current state and future potential of the photonics sector in Finland, examining the country's strengths in various areas and identifying opportunities for growth and innovation.

## Industry Overview

The Finnish Photonics industry is a significant and growing sector that plays a crucial role in the country's economy and technological advancement. Photonics drives and enables innovation across various industries, including healthcare, communications, and manufacturing. This section provides an in-depth look at the strengths, economic contributions, and future potential of the Finnish photonics industry.

### Strengths of the Finnish Photonics Sector

Finland has emerged as a world leader in photonics research and innovation, supported by a thriving ecosystem of academic and industrial players. The country has a long tradition of high-tech research and industry, with significant expertise in photonics since the 1960s. Finnish companies and research institutions have pioneered numerous photonics-related technologies, making the nation an ideal place for photonics innovations, commercialization of new products, and the growth of companies in the field. The Finnish photonics sector excels in optical imaging and sensing, micro- and nanophotonics, and laser and XR technology. Establishment of foreign photonics companies in Finland and the acquisition of Finnish photonics companies by foreign enterprises is a testament to the high regard for Finnish photonics expertise. The PREIN Flagship is a unique and essential component of Finland's photonics industry development, facilitating research and industry collaboration

### Economic Impact and Export Activities

The Finnish photonics industry is export intensive. Key export markets are in Europe, Asia, and the USA, and emerging markets in Latin America. Approximately 62% of Finnish photonics companies are small enterprises with an annual turnover of around €5 million. The industry's growth has remained strong, with a 25% increase in size since 2020, and a projected annual growth rate of 26% over the next three years.

Photonics manufacturing is the largest target market within the Finnish photonics sector. The primary output includes the manufacture of optical components, systems, and instruments. It accounts for 60% of the industry's production

while the remaining output consists of services, raw materials, and distribution.

### Opportunities for Growth

The key drives of growth for Finnish photonics companies are forming partnerships both domestically and internationally, effective recruitment strategies, and thorough market and technology analyses. The Finnish photonics ecosystem is open to international collaboration, with Photonics Finland, the Finnish national association for Photonics, playing a pivotal role in facilitating market access and partner connections. The future potential of the Finnish photonics industry lies in its ability to innovate and expand into emerging markets. Areas such as quantum photonics, biophotonics, and integrated optics present significant opportunities for growth. Collaborative initiatives like the PREIN Flagship are crucial in driving innovation and fostering research collaboration between academia and industry. The PREIN Flagship facilitates joint research projects, access to research infrastructure, and collaboration opportunities, significantly contributing to the growth and development of the photonics sector.

**Key Points:**

- The Finnish photonics industry includes over 300 companies.
- In 2023 the Finnish photonics industry records a total annual turnover exceeding of €2 billion, directly employing more than 6,000 people.
- The sector is highly export-oriented, with major markets in Europe, Asia, and the USA, and has seen 25% growth since 2020.
- Photonics manufacturing is the largest market segment, accounting for 60% of the industry's production.
- Key growth facilitators include finding domestic and foreign partners, recruiting, and market and technology analysis.

## Research Overview

Photonics research in Finland is at the forefront of technological innovation, driven by world-class universities and research institutes. This section provides a look at the institutions of Finland's photonics research landscape and identifies key opportunities for future growth and innovation.

### Key Research Institutions

**University of Eastern Finland[1] (UEF**) is home to the Center for Photonics Sciences, which combines all research and education in optics and photonics. The center focuses on electromagnetic coherence and polarization theories, light-matter interactions, large-scale fabrication of optical micro and nanostructures, and 3D printed macroscopic optics. UEF's research also covers photonics materials, including carbon-based nanomaterials, and integrated optics, facilitating the miniaturization of optical systems.

**Aalto University[2] (aalto)** is actively involved in photonics research, particularly focusing on quantum photonics and nanophotonics. The university's research efforts are driven by interdisciplinary collaboration, integrating various scientific fields to advance both fundamental science and practical applications in photonics. Aalto's contributions include developing advanced photonic materials and devices, which have significant implications for information technology, healthcare, and other industries. The university also participates in national and international research collaborations, enhancing its impact and reach in the global photonics community.

**Tampere University[3] (TAU)** focuses on developing new light sources and methods to utilize and control light properties. Key research areas include nonlinear optics, metamaterials, quantum optics, ultrafast photonics, epitaxy, nanostructuring, and the integration of various III/V semiconductors and functional materials for light-driven technologies. Applications of this

1. www.uef.fi
2. www.aalto.fi
3. www.tau.fi

research extend to innovative solar energy technologies, medical applications, soft robotics, and precise measurement techniques.

**University of Helsinki[1] (helsinki)** integrates photonics research into its physics, chemistry, and medical faculties. Key research areas include microscopy, X-ray spectroscopy and tomography, aerosol optics, and astrophysics applications. The Department of Chemistry at Helsinki focuses on nonlinear optics and photoacoustics, developing new spectroscopy and microscopy methods for various applications, including environmental monitoring and medical diagnostics.

**University of Jyväskylä[2] (JYU)** hosts a nanoscience center where interdisciplinary research in physics, chemistry, and biology is conducted. Research topics include nanoscale interactions and properties, molecular nanoscience, and nanospectroscopy. This center supports a multidisciplinary approach to photonics research, contributing to advancements in both fundamental and applied sciences.

**University of Oulu[3] (oulu)** focuses on photonics research related to electrical engineering and measurement technologies. Key areas include advanced optical and electrical measurement techniques, biomedical measurements, photonics, and printed electronics. The university's research efforts aim to develop innovative solutions for various industrial applications.

**University of Turku[4] (UTU)** conducts research in photonics through its physical and chemical sciences programs. Research topics include the development of new materials for biomedical and electronic applications, with a strong emphasis on integrating photonics into practical and commercial technologies.

**VTT Technical Research Centre of Finland[5] (VTT)** is a crucial player in the photonics research landscape. VTT conducts high-impact research in areas such as optical sensors, imaging systems, and laser technologies. The center collaborates extensively with industry partners to translate research findings into practical applications, enhancing the competitiveness of Finnish photonics on the global stage.

**Opportunities for Growth**

The future of Finnish photonics research lies in its ability to innovate and expand into emerging areas. Significant opportunities for growth exist in fields such as quantum photonics, biophotonics, and integrated optics. The development of pilot lines and advanced laser technologies also presents substantial potential for research expansion.

Collaborative initiatives like the PREIN Flagship are essential in driving research advancements. PREIN facilitates joint research projects, access to state-of-the-art research infrastructure, and collaboration opportunities between academia and industry. Such initiatives are crucial for translating research findings into practical applications and fostering innovation across the photonics sector.

The Finnish photonics research community is well-positioned to address global challenges through interdisciplinary collaboration and innovative research. By continuing to leverage its strengths and exploring new opportunities, Finland can maintain its leadership in photonics research and contribute significantly to technological advancements worldwide.

**Key Points:**

- Leading institutions include UEF, aalto, TAU, helsinki, oulu, UTU, and VTT
- Key research areas: quantum photonics, nanophotonics, optical sensors, imaging systems, and laser technologies.
- Interdisciplinary collaboration integrates physics, chemistry, biology, and engineering.
- Growth opportunities in quantum photonics, biophotonics, integrated optics, and advanced laser technologies driven by initiatives like PREIN.

1. www.helsinki.fi
2. https://www.jyu.fi/
3. https://www.oulu.fi
4. www.utu.fi
5. www.vtt.fi

## Education Overview

Photonics education in Finland is a cornerstone for the development of a skilled workforce essential to the industry's growth and innovation. Finnish universities offer comprehensive programs that integrate theoretical knowledge and practical applications, preparing students to excel in various fields within photonics. Academic research and education are closely intertwined, with research-informed degree programs providing the workforce with theoretical competencies and application skills. The demand for master's and doctoral graduates in Finnish photonics companies is constantly growing due to the sector's rapid expansion.

**University of Eastern Finland (UEF)** has a rich history in photonics education, spanning over fifty years, and offers a wide range of programs at all degree levels. UEF is the only higher education institution to offer a Master of Science (Technology) in Photonics[5] degree program which will equip students with expert skills needed globally in careers in optics and photonics. UEF also coordinates a joint Erasmus Mundus master's program, Intelligent Photonics for Security Reliability Sustainability and Safety (iPSRS)[1], and participates in two additional Erasmus Mundus master's programs related to photonics (Master of Science in Imaging and Light in Extended Reality (IMPLEX)[3] and Master's degree in Applied Colour Science (COSI)[4]). UEF maintains strong industry ties to enhance graduate employability.

**Tampere University (TAU)** offers robust photonics education through its International Master's Program in Photonics Technologies[6], which covers a broad spectrum from light-matter interactions to advanced nanofabrication methods and measurement techniques. The university also coordinates the doctoral pilot program in Innovative Doctoral Education Ecosystem for Photonics (I-DEEP)[2], established based on the activities of the PREIN Flagship. This program provides students with opportunities to delve into specialized research and develop advanced skills in photonics technologies.

**Aalto University (aalto)** integrates photonics into its master's program in Nano and Radio Sciences, focusing on electromagnetic radiation modeling, optics, and materials science. Specialization in Photonics and Nanotechnology equips students with theoretical and practical skills applicable in various high-tech industries. Aalto's Doctoral Program in Electrical Engineering allows for further specialization in photonics, supporting research and development in areas such as energy production, biomedical applications, and communication technologies.

**University of Jyväskylä (JYU)** offers a master's degree in Nanoscience, which combines physics, chemistry, and biology in a multidisciplinary approach. Students can choose to major in chemistry, physics, or cell and molecular biology, gaining a broad skill set that is highly applicable to photonics research and industry.

**University of Oulu (oulu)**, photonics education is integrated into the Electrical Engineering master's degree program. Students can specialize in photonics and measurement technology, learning advanced optical and electrical measurement techniques applicable to biomedical measurements, photonics, and printed electronics.

**University of Helsinki (helsinki)** provides a master's program in Materials Research, encompassing physics, chemistry, biology, medical sciences, mathematics, and computer science. One of the study tracks focuses on optics and photonics, offering a comprehensive education that bridges multiple scientific disciplines.

**University of Turku (UTU)** includes photonics as a theme within its master's program in Physical and Chemical Sciences. This program aims to train graduates for research and development of new materials, particularly for biomedical and electronic applications.

### Additional Educational Initiatives

Beyond formal degree programs, the PREIN Flagship partners offer a variety of courses, training sessions, and summer schools

1. https://www.master-photonics4security.eu/
2. https://prein.fi/i-deep/
3. https://www.imlex.org/
4. https://cosi-master.eu/
5. https://www.uef.fi/en/degree-programme/masters-degree-programme-in-photonics
6. https://www.tuni.fi/en/study-with-us/photonics-technologies

throughout the year for both professionals and students. These programs often involve collaboration with industry, ensuring that the education provided aligns with current market needs and technological advancements. Ongoing education and training initiatives, developed in partnership with regional entities

and other funding sources, further support the continuous professional development of individuals in the photonics sector.

**Key Points:**

- Finnish universities offer extensive photonics education at all levels, blending theoretical and practical learning.
- Strong industry ties and international joint degrees attract global students and ensure industry relevance.
- PREIN Flagship partners provide additional training and courses in collaboration with industry to stay current with market needs.
- Programs provide continuous educational pathways from undergraduate to doctoral levels, with international collaborations enhancing scope.

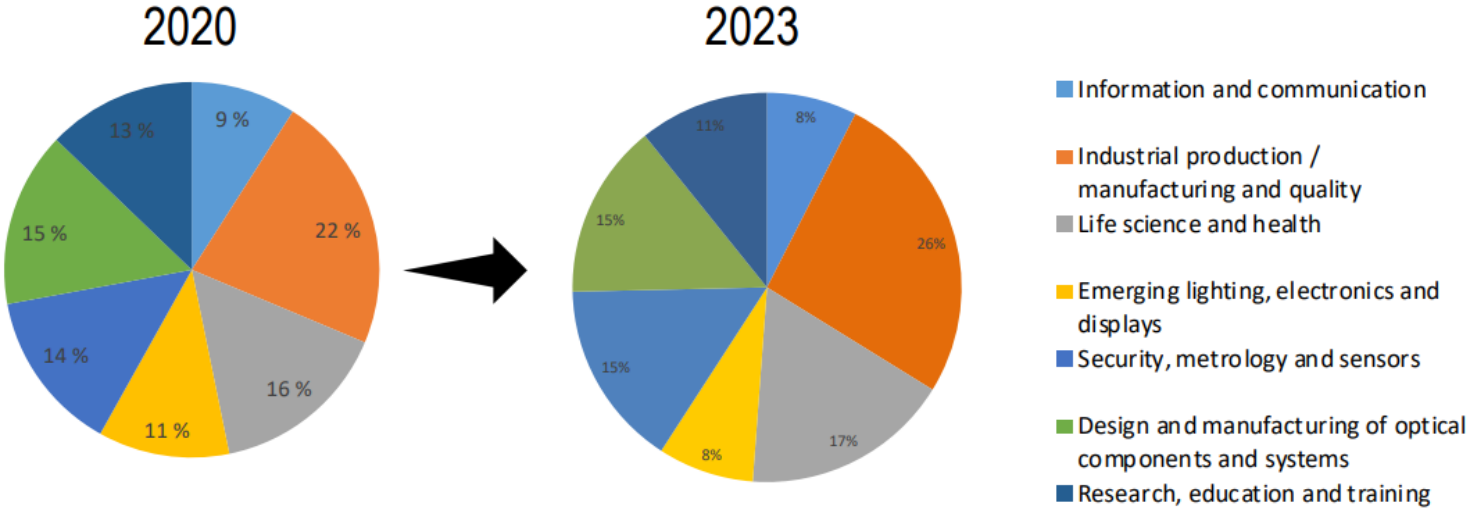
## Market Overview

The Finnish photonics market is integral to the national economy and technological innovation, with significant growth potential and diverse applications. The industry has shown substantial growth, with an annual turnover exceeding €2 billion and directly employing more than 6,000 individuals. Projections indicate continued expansion at an annual rate of 26% over the next three years, driven by advancements in various photonics applications and increased global demand.

The Finnish photonics market encompasses several key segments, including industrial manufacturing, healthcare, and telecommunications. Emerging segments such as quantum photonics and biophotonics offer significant opportunities for future growth and innovation. The industry is highly export-driven, with major markets in Europe, the USA, and Asia, and a strong export intensity reflecting the global demand for Finnish photonics products.

A critical component of Finland's photonics strategy is its integration with the "Chips from the North" semiconductor initiative[1], which emphasizes the importance of photonic technologies alongside advanced materials, microelectromechanical systems (MEMS), and quantum technologies. Photonics plays a vital role in semiconductor innovations, particularly in data communication, sensing, and integrated photonic circuits. This strategy aims to attract international investments and enhance Finland's position in the global market through increased R&D investments, fostering industry-academia collaborations, and establishing specialized education programs to meet the growing demand for skilled professionals.

**Industrial manufacturing continues to be the most important target market for photonics companies**




1. https://teknologiateollisuus.fi/wp-content/uploads/2024/07/Chips-from-the-North-Summary.pdf

Alongside its promising growth, the Finnish photonics market faces several challenges, including a talent shortage, regulatory issues, and high initial costs for market entry. These challenges can be addressed through targeted education programs, streamlined regulations, and support for startups is crucial for sustaining market growth.

Looking ahead, the Finnish photonics market is poised for continued growth and innovation. By 2030, the industry aims to significantly increase its global market share, driven by advancements in quantum technologies, biophotonics, and integrated optics. Increased collaboration between industry, academia, and government will be essential to ensure sustained growth and global leadership in photonics.

**Key Points:**

- Rapid growth with over €2 billion in annual turnover and a 26% projected growth rate.
- Strong export orientation, integrating with the "Chips from the North" semiconductor strategy.
- Key opportunities in quantum photonics, biophotonics, and integrated optics.
- Challenges of talent shortages and regulatory issues are opportunities for growth through targeted education and streamlined regulations.

## Employment of Graduates in Photonics Industry

The Finnish photonics sector relies heavily on the steady influx of skilled graduates from the country's robust educational programs. This chapter examines how well graduates from photonics-related programs are integrated into the industry, their employment prospects, and the alignment between educational outcomes and industry needs.

**Employment Rates of Graduates**

Graduates from photonics programs in Finland enjoy high employment rates, with most securing relevant positions within six months of graduation. This success is attributed to the strong industry-academia collaboration that ensures the curriculum meets industry requirements. Continuing such success is highlighted further in the roadmap vision and specific action recommendations.

**Types of Jobs**

Photonics graduates find employment in various roles, including research and development, manufacturing, technical support, and sales. Key employers include multinational corporations, innovative startups, and research institutions.

**Industry Demand**

The demand for photonics graduates is projected to grow, driven by advancements in telecommunications, healthcare, and industrial manufacturing. The industry's expansion into emerging fields like quantum photonics and biophotonics further enhances job prospects for graduates.

**Skills and Competencies**

Employers in the photonics industry value graduates with strong analytical and problem-solving skills, proficiency in optical design software, and practical laboratory experience. Educational programs are continuously updated to include the latest technological advancements and industry practices.

**Collaborations and Internships**

Finnish universities have established strong partnerships with photonics companies, providing students with internship opportunities and hands-on experience. Programs like the PREIN Flagship facilitate these collaborations, ensuring that students are well-prepared for the workforce.

**Challenges and Opportunities**

While the employment outlook is positive, challenges such as the need for continuous skill development and adaptation to rapidly changing technologies remain. Opportunities for enhancing employability include specialized training programs, certifications, and participation in industry conferences and workshops.

**Key Points:**

- High employment rates for photonics graduates, with most finding relevant jobs within six months.
- Diverse job roles in R&D, manufacturing, technical support, and sales.
- Growing demand for graduates, especially in emerging fields like quantum photonics and biophotonics.
- Strong industry-academia collaboration, with numerous internships and hands-on training opportunities.

1. Surveys and Brochures
2. Photonics Finland Annual Report 2023
3. PREIN Annual Report 2023

# Global Challenges and Photonics Technologies

Being a key enabling technology Photonics provides the means to address the world's most pressing challenges. From climate change and energy efficiency to healthcare, security, dual-use applications, and digital transformation, photonics-driven innovation plays a critical role in creating sustainable and technologically advanced solutions.

**Climate Change & Energy Efficiency**

The increasing demand for energy and the urgent need to reduce carbon emissions require more efficient and sustainable technologies. Currently, traditional energy production and industrial processes are significant contributors to global warming and those need to evolve.

Photonics is a key technology to enhance energy efficiency and sustainability in multiple ways. Advanced photovoltaic systems improve energy conversion efficiency, while solid-state lighting (LED and OLED) significantly reduces electricity consumption. Additionally, optical sensors enable precise monitoring of environmental conditions, supporting emission control and climate change mitigation strategies.

**Digitalization & Hyper Computing Performance**

The rapid growth of data traffic, artificial intelligence (AI), cloud computing, and internet of things (IoT) applications requires faster, more secure, and energy-efficient communication networks and data processing. Conventional electronic data transmission systems struggle to meet these increasing demands. Their high energy consumption and slow data processing do not meet future requirements.

Photonics technologies drive fiber-optic communication, providing ultra-fast, high-capacity, and energy-efficient data transmission. Silicon photonics and photonic integrated circuits (PICs) enable compact and cost-effective solutions for data centers and next-generation telecommunication networks, facilitating optical data processing. These advancements are critical for supporting the expansion of 5G, future 6G networks, and AI-driven digital services.

**Healthcare & Biomedical Innovations**

The need for early disease detection, non-invasive medical procedures, and improved healthcare diagnostics is growing worldwide, especially with aging populations and emerging pandemics. Drug development, new imaging models, and advanced measurement methods play a crucial role.

Photonics technologies enable advanced medical imaging techniques such as optical coherence tomography (OCT), fluorescence imaging, and Raman spectroscopy, which allow for early and accurate disease diagnosis. Laser-based treatments are widely used in eye surgery, dermatology, and cancer therapy, while biosensors facilitate real-time health monitoring. These innovations contribute to improved patient outcomes, disease prevention and early diagnosis significantly reducing healthcare costs.

**Security, Defense, & Quantum Technologies**

Growing cybersecurity threats, geopolitical tensions, the need for enhanced surveillance, and secure communication create a demand for advanced security technologies. The defense industry requires new technologies and efficient production methods, playing a significant role in national security. At the same time quantum technology challenges remain in achieving stable computation, effective measurements, and high-speed data transfer.

Quantum photonics offers breakthroughs in secure communication through quantum key distribution (QKD), which provides an unbreakable encryption method. Optical sensors and imaging systems enhance surveillance and reconnaissance capabilities in defense and aerospace applications. PICs technology enables stable quantum computing at room temperature. However, in the quantum technology roadmap, the first real-world applications will emerge in quantum sensing and quantum communication. The defense industry also has a growing demand for new materials that reduce costs, lighter products, and new functionalities while ensuring supply security.

**Manufacturing, Industry & Automation**

The need for more efficient, precise, and automated manufacturing processes is increasing due to labor shortages and the demand for high-quality production. In the world and also in Finland laser technology, various XR solutions, and advanced machine vision capabilities enable manufacturing to remain competitive.

Photonics plays a vital role in laser-based manufacturing, enabling high-precision cutting, welding, and additive manufacturing. Machine vision systems equipped with photonics sensors improve automation, quality control, and efficiency in smart factories. The "Designed in Finland SoC"[1] initiative also supports advanced photonics integration in industrial applications, strengthening Finland's role in high-tech manufacturing.

**Finland's Role in Addressing Global Challenges**

Finland has strong expertise in photonics research and industry, positioning the country as a leader in developing innovative solutions to global challenges. With key photonics innovation hubs and organizations such as Photonics Finland, including the PREIN Flagship Programme, Finland is driving advancements in laser technologies, quantum photonics, and photonic integration. By fostering collaboration between academia, industry, and international partners, Finland can contribute significantly to the global photonics landscape and create new economic opportunities.

1. https://sochub.fi/

# Growing the Finnish Photonics Ecosystem since 1996

Founded in 1996[1], the Finnish Optical Society (FOS) operated for 18 years as a community of academics working in optics and photonics in Finland. The interest among optics and photonics researchers in the country was evident by reaching 100 members within the first year of operations. Among those were also company representatives and people interested in optics and photonics in general. Already in its first year of its operation, FOS was accepted as a member of the European Optical Society (EOS).

Besides being the bridge between industry and academia FOS strived to strengthen the community. This is how an annual national event, The Optics Days, was established. In February 1997 the first community gathering was held in Tampere with a dominantly academic program, five invited domestic presentations, 45 poster presentations and 5 exhibitors. After this, Optics Days were organized in different cities (Joensuu, Jyväskylä, Kajaani, Kuopio, Oulu, Tampere, Turku), travelling alike a road show, to reach all parts of Finland. In 2013 the event expanded to include photonics, The Optics and Photonics Days (OPD), and in 2024 OPD held in Helsinki reached record-breaking numbers; with 438 participants, 80 posters, and 45 exhibitors from all over the Europe, US, and Japan. The event now includes both Academic and Industrial program, Student event, Job fair, and Matchmaking.

In February 2012, a 'Photonics Finland' project was launched as a two-year initiative aimed at assembling a national photonics network, or more precisely, a national technology platform, of different actors in the field. Photonics Ecosystems in Europe were rapidly growing at the time and Finland's presence was missing. The project was implemented to bridge this gap by forming cooperation with Joensuu Science Park and the Optoelectronics Research Centre of the University of Tampere as a spin-off project of the Nano Competence Centre program. This business-led cooperation fostered closer cooperation with photonics companies to promote the field in Finland as well as increasing interdisciplinary and inter-industry dialogue. After six months of operations and through in-person company contacts, about 100 companies expressed interest in joining the planned project and the photonics community. A considerable number of negotiations followed on how to form an academy-industry community. In May 2014 a decision was made to officially change the name of FOS the Finnish Photonics Society (Business ID 1455727-2) – Photonics Finland (PF) and update the society rules and operation.

Photonics Finland's role as a bridge builder between academic and industrial activities and as a connecting link between these two sectors was established. At the same time, an internationally unique operating model was created. The chairmanship of the board has changed alternately between the academic and industrial actor every two years. With all this put in place PF set goals to increase the number of members and reach international visibility. The first steps were made by joining the European Photonics Industries Consortium (EPIC) as a community member.

Since 2014, the practical activities of the association have been carried out by its office staff, which was not possible during the FOS era. The office actively brought EU project in, through which the competency, recognition, and the Finnish Photonics image was built. Moreover, the funding is a substantial source to maintain the operations of running community activities. The operating budget of PF office is now approaching half a million euros. Obtaining funding from the European network, with a relatively small volume and shorth duration span is a challenging task. Over the years it has been successfully achieved, however with the growth rate of the community there is a need for sustainable national funding.

Another path PF office took in growing the community and gaining international recognition is by participating in corporate exhibitions. This was delivered by creating a joint exhibition pavilion for Finnish companies. Until 2016, the arrangements were aimed at the Optatec fair, which was then followed by major events Photonics West, San Francisco and Laser World

1. https://www.photonics.fi/fotoni/fotoni-1-2024/

of Photonics, Munich. This became a trademark of Photonics Finland.

In addition to these key annual events, PF hosts a variety of webinars and seminars, courses, info sessions, coffee breaks, and utilizes its platform to promote other organizations photonics related events. In 2019 Finnish Photonics research reached a big milestone by becoming one of the Finnish Flagship programs managed by the Research Council of Finland. This is a testament to photonics being recognized nationally to provide new and unique ways for R&D&I.

All the above contributed to Finland being recognized as a 'lighthouse' region of European Photonics[3, 4]. In international projects Finnish Photonics is an equal and leading partner now, with ecosystem and technology knowhow that other European clusters eagerly learn from. In 2024 PF received a BRONZE Label Certificate for Cluster Management Excellence[2].

In 2016, PF counts 206 individual members and 43 corporate and community members. Same year the industry survey revealed that there are approximately 200 companies or organizations in Finland for which photonics is either directly or indirectly a significant industry. The turnover of photonics in Finland was approximately €1 billion and approximately 4,000 employees worked directly in photonics. In spring 2020, the number of companies, as well as the turnover and personnel, grew at an annual rate of approximately 10%. The last survey collected in 2023 shows that the photonics industry has a 15-20% annual growth rate, approximately 300 companies in the field of photonics or utilizing photonics, which employ approximately 6,000 people and the companies' turnover exceeded the 2 billion EUR mark, half of which is exported. This suggested that the progress and growth of Finnish Photonics needs to be monitored closely, and the survey will be collected every two years, with new results coming in summer 2025. Currently, PF counts over 250 individuals and over 120 organizational members (of which 108 are company members).

In 2019 Photonics has been recognized by the parliament of Finland as a key-enabling technology for improving the Finnish economy. This impacted the recognition of Finnish Photonics ecosystem by national decision makers and opened the path to discussing future growth opportunities.

Approaching soon 30 years of development, the Finnish photonics community has grown from an academic-centered society to a company driven triple helix ecosystem.

## Finnish Photonics Vision 2030

The vision for Finnish Photonics for 2030 is:

- Photonics is inclusive and recognized as an attractive future career choice.
- Finland is a forerunner in sustainable future through collaborative photonics research, technology development, and innovation.
- Finland develops cutting-edge technology and successful companies, gaining global recognition.
- Finland has one of the leading photonics hubs in Europe.

To achieve this the Finnish Photonics industry will double its revenue from €2 billion to €4 billion and increase employment from 6,000 to 12,000 professionals. This ambitious growth trajectory is driven by cutting-edge research, strategic investments, and a strong ecosystem that fosters innovation and global collaboration.

**A Thriving and Inclusive Industry**

Photonics in Finland will be recognized as a key enabling technology that enhances multiple industries, including healthcare, telecommunications, manufacturing, and environmental monitoring. By positioning photonics as an appealing career path, the sector will continue to attract top talent, offering competitive opportunities for researchers, engineers, and business professionals.

Education and workforce development are essential components of this vision. Finnish universities and research institutions will further strengthen their photonics programs, ensuring a steady supply of highly skilled graduates. Industry-academia collaboration will remain a

1. https://www.eduskunta.fi/FI/valiokunnat/tulevaisuusvaliokunta/julkaisut/Sivut/fotoniikasta-valoa-suomen-hyvinvointiin.aspx
2. https://www.photonics.fi/2024/03/28/photonics-finland-have-been-awarded-with-the-bronze-label-recognition-of-the-european-commission-cluster-excellence-initiative/
3. https://www.photonics.fi/photonhub-europe/
4. https://www.photonhub.eu/partnership/

priority, facilitating knowledge transfer and hands-on experience for students. Initiatives such as the PREIN Flagship program and national doctoral education networks will play a crucial role in maintaining Finland's leadership in photonics research and innovation. These initiatives will feed the whole value chain with new and modern ways to industry-academia collaboration.

**Global Recognition through Innovation and Collaboration**

Finland's photonics sector will gain global recognition through its excellence in technology development, commercialization, and industry collaboration. Finnish companies will leverage their strengths in optical imaging, sensors, laser technology, and integrated photonics to create world-class solutions that address global challenges.

By 2030, Finland will have one of the strongest photonics ecosystems in Europe, supported by well-established national and international partnerships. Collaborative research and joint ventures with leading photonics hubs in Europe, the USA, and Asia will drive innovation and market expansion. Stronger ties with international companies, research institutions, and funding agencies will ensure that Finland remains at the forefront of photonics advancements.

**Ecosystem Growth and Market Expansion**

The Finnish Photonics industry will continue to be highly export-driven, with an increased presence in global markets. Investments in photonics pilot lines, national innovation hubs, and digitalization will enable companies to scale their technologies and enter new application areas such as quantum photonics, biophotonics, and integrated optics.

The Finnish government and industry stakeholders will ensure sustained growth and competitiveness by working together to create policies and funding structures that support photonics startups and SMEs. Finland's participation in European research initiatives, such as Horizon Europe, will further enhance its role as a leader in photonics-driven innovations.

**A Sustainable Future Powered by Photonics**

As Finland advances towards 2030, sustainability will remain a key focus in photonics development. The industry will contribute to green technology solutions, energy efficiency, and circular economy principles. Photonics-enabled advancements in solar energy, smart lighting, and energy-efficient data communication will play a pivotal role in Finland's commitment to carbon neutrality and sustainable industrial growth.

By achieving these milestones, Finland will not only double its photonics industry but also reinforce its reputation as a global leader in photonics research, technology development, and commercialization. The strong foundation built through collaboration, education, and innovation will ensure long-term success and economic growth for the Finnish photonics sector beyond 2030.

This roadmap presents the recommendations of the Finnish Photonics community on how to achieve this vision. Through strategic initiatives, policy support, and continued investment in research and education, Finland is well-positioned to reach its ambitious goals for 2030.

# Action Recommendation

In this chapter we propose recommendations for national actions needed to strongly support photonics to achieve the goals set for 2030. These actions fall into six main categories:

- National Photonics Pilot Line
- Continuing and Expanding the PREIN Flagship Program
- National Photonics Growth Engine
- Workforce Growth and Development
- Enhancing Finland's International Influence and Export in Photonics
- Strengthening the Photonics Ecosystem

## National Photonics Pilot Line

**Objective:** To establish a national photonics pilot line to support the development, testing, and commercialization of new photonics technologies and applications in Finland. This will serve the entire European market with new materials and photonics technologies which, at present, can only be achieved in Finland.

**Background and Justification:** The establishment of a national photonics pilot line is crucial for maintaining and enhancing Finland's competitive edge in the photonics sector. Finland boasts a comprehensive and robust photonics ecosystem, leveraging expertise from various leading institutions and universities across the country – VTT, UEF, TAU, and oulu. This collective expertise positions Finland as a key player in the European photonics landscape.

VTT is focusing on developing the hybrid (and heterogeneous) integration of PICs that contain passive Si and/or SiN waveguides, primarily made at VTT, and fast photonic modulators, primarily made at UEF. These hybrid PICs may also include Ge-based photodiodes, light sources, nonlinear functions, and other photonic functions. The hybrid PICs can be integrated with electronic integrated circuits (EIC) for driving/controlling the PICs or reading/amplifying the detector output signals.

Hybrid integration of other components and functions on top PIC's can be based on flip-chip bonding, micro-transfer-printing (MTP), heterogeneous integration (local layer transfer), or monolithic wafer-level integration. These integration steps can be performed on either wafers or chips, and at either UEF or VTT.

Two promising modulator technologies are thin-film lithium niobate (TFLN) and plasmonics. UEF can develop these modulators or other fast photonic components, which would then be integrated onto VTT's PIC wafers by either UEF or VTT with sub-micron alignment accuracy. This combination of low-loss passive PICs and fast photonic components would address the growing need for small, inexpensive, and power-efficient PICs in multiple application areas, such as artificial intelligence (AI), quantum computing, data center interconnects, lidars, and fiber-to-the-home.

Additionally, Tampere University and the University of Oulu bring significant expertise in packaging technologies, which are essential for the integration and commercialization of photonic devices.

By leveraging existing expertise and facilities across these institutions, Finland can create comprehensive solutions that serve the entire European market. A National Photonics Pilot Line would be integrated with the Finnish Semiconductor Competence Center (FiCCC)[1] project and complement its innovation with key technological developments. This will elevate Finland's capabilities to offer nationally significant expertise to other European partners and attract investments to Finland. This will make Finland an attractive country for research, development, and manufacturing.

**Actions:**

**Infrastructure Development:** Invest in state-of-the-art equipment and facilities, including cleanrooms, advanced manufacturing tools, and testing laboratories, to support the development and testing of photonics technologies.

**Collaboration and Networking:** Promote collaboration between research institutions, universities, and industry partners. Establish partnerships with international photonics research centers to facilitate knowledge exchange and joint projects.

1. https://www.ficcc.eu/

**Support for Startups and SMEs:** Provide support for photonics startups and SMEs through access to the pilot line facilities, mentorship programs, and funding opportunities. This support will help these companies to scale their innovations and bring them to the market.

**Education and Training:** Develop educational and training programs to build a skilled workforce capable of operating and utilizing the pilot line facilities. Offer hands-on training and workshops for students, researchers, and industry professionals.

**Commercialization of Innovations:** Create mechanisms to support the commercialization of innovations developed at the pilot line. This can include technology transfer programs, intellectual property management, and market access support.

**Securing Funding:** Ensure sufficient funding for the establishment and operation of the pilot line. This funding should come from both public and private sector investments. An estimate of a total budget for building a comprehensive National Photonics Pilot Line is €35 million, with two thirds of the budget being needed for premises and equipment, and one third for personnel.

**Expected Outcomes:**

**Accelerated Innovation:** Faster development and commercialization of new photonics technologies and applications.

**Enhanced Competitiveness:** Strengthened global competitiveness of Finland's photonics industry.

**Economic Growth:** Increased economic activity and job creation in the photonics sector.

**Skilled Workforce:** Development of a highly skilled workforce capable of driving innovation in photonics.

**International Collaboration:** Enhanced international collaboration and knowledge exchange in the field of photonics.

## Continuing and Expanding the PREIN Flagship Program

**Objective:** To strengthen the Flagship's exiting impact and expand it to include new and emerging photonics technologies, pilot lines, and educational initiatives.

**Background and Justification:** The PREIN Flagship[1] has been instrumental in driving the growth of Finland's photonics sector, laying a solid foundation for fostering innovation and future breakthroughs. Together with FinnLight[2], the national roadmap infrastructure for photonics, PREIN has created a robust foundation for innovation and collaboration, benefiting both research and business. Now operating at full speed after six years of success, it is essential to continue and expand the Flagship activities to fully capitalize on the progress made.

**Actions:**

**Expanding the Flagship's scope:** Including new and emerging photonics technologies and applications—such as optical computing, medical diagnostics, wearable health monitoring, LIDAR, quantum photonics and many more—will unlock further potential.

Furthermore, PREIN aims to benefit significantly from the newly established pilot lines in Finland under the EU Chips Act. These pilot lines are designed to accelerate the development and production of advanced photonic and semiconductor technologies, providing state-of-the-art manufacturing capabilities that complement the research and innovation efforts of PREIN. By leveraging these resources, the Flagship can enhance developments in photonic integrated circuits, sensor technologies, and quantum photonics, further strengthening Finland's leading position in the European photonics ecosystem.

**Collaboration and Networking:** Strengthening international collaboration with leading research institutions and companies worldwide is equally important. Joint research initiatives and exchange programs will facilitate the transfer of knowledge and expertise, amplifying the Flagship's global impact.

1. www.prein.fi
2. https://finnlight.fi/

**Education and Training:** By integrating educational opportunities and continuous professional training, the Flagship will help educate a next generation of experts while enhancing the skills of existing professionals. PREIN can build on the Innovative Doctoral Education Ecosystem for Photonics I-DEEP doctoral pilot program by expanding its reach to include additional partners. This will foster a broader network of collaborations, enhancing the training of future photonics experts while driving research and innovation through a more diverse and integrated ecosystem.

**Securing Funding:** To sustain this momentum, it is crucial to extend the PREIN Flagship status through 2030, with long-term funding being a key priority. New flagship funding until 2030 will ensure the continuation and expansion of the PREIN Flagship activities and its major contribution to the national Photonics ecosystem

## National Photonics Growth Engine

**Objective:** To establish a National Photonics Growth Engine in Finland - a comprehensive photonics innovation hub that leverages existing expertise and infrastructure to create new paths for photonics business growth.

**Background and Justification:** Photonics is also recognized as a Key Digital Technology[1] that radically transforms traditional industries. It is essential for new applications powering Industry 4.0 and addressing global societal and environmental challenges. Photonics technologies are being used to create superior and previously unimaginable products across various sectors, including but not limited to sustainable energy, agrifood, healthcare, security, smart transport, building, and communications systems. Most critically, photonics is a key enabling technology for transforming production methods and business models in European manufacturing, which has been losing its competitive edge due to globalization.

99% of European businesses are small and medium-sized enterprises (SMEs)[2]. They provide jobs to more than 85 million European citizens and form the backbone of the EU economy. Besides the economic impact, SMEs are the engine of innovation. With over 5000 companies the European photonics industry is SME driven[3]. It is estimated that only about 200 companies have more than 250 employees. SMEs are therefore particularly important for the European photonics industry for the volumes they represent.

In Finland, about 62% of companies specializing in photonics technologies are SMEs and start-ups and their number is growing[4]. These companies need access to services, facilities, and resources to scale up their innovations from prototypes to production.

To accelerate the uptake of photonics technologies by European industry, and thereby boost competitiveness and foster new business models, Finland aims to establish a National Photonics Growth Engine. This hub will be deeply integrated within the wider ecosystem of innovation hubs and manufacturing across Europe, ensuring maximum coverage, leverage, impact, and long-term sustainability.

**Actions:**

**Infrastructure Development:** Invest in state-of-the-art equipment and facilities, including cleanrooms, advanced manufacturing tools, and testing laboratories, to support the development and testing of photonics technologies.

**Collaboration and Networking:** Promote collaboration between research institutions, universities, and industry partners. Establish partnerships with international photonics research centers to facilitate knowledge exchange and joint projects.

**Support for Startups and SMEs:** Provide support for photonics startups and SMEs through access to the Growth Engine facilities, mentorship programs, and funding opportunities. This support will help these companies to scale their innovations and bring them to market.

**Education and Training:** Develop educational and training programs to build a skilled workforce capable of operating and utilizing the Growth

1. https://digital-strategy.ec.europa.eu/en/library/key-digital-technologies-keys-our-digital-future-brochure
2. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20241025-1
3. https://www.photonics21.org/download/ppp-services/photonics-downloads/Broschure-Photonics-PPP-Services-to-European-SMEs_Final_C1.pdf
4. https://www.photonics.fi/wp-content/uploads/2023/06/Photonics-Industry-in-Finland-2023.pdf

Engine facilities. Offer hands-on training and workshops for students, researchers, and industry professionals.

**Commercialization of Innovations:** Create mechanisms to support the commercialization of innovations developed at the Growth Engine. This can include technology transfer programs, intellectual property management, and market access support.

**Securing Funding:** Ensure sufficient funding for the establishment and operation of the Growth Engine. This funding should come from both public and private sector investments, including European Union programs such as Horizon 2020.

**Expected Outcomes:**

**Accelerated Innovation:** Faster development and commercialization of new photonics technologies and applications.

**Enhanced Competitiveness:** Strengthened global competitiveness of Finland's photonics industry.

**Economic Growth:** Increased economic activity and job creation in the photonics sector.

**Skilled Workforce:** Development of a highly skilled workforce capable of driving innovation in photonics.

**International Collaboration:** Enhanced international collaboration and knowledge exchange in the field of photonics.

**Strategic Mission:** The National Photonics Growth Engine will provide European photonics and non-photonics companies, particularly SMEs and mid-caps, with open access and guided orientation to a broad range of services and capabilities. These include:

*"Test-before-invest" Innovation Support:* Capabilities along the full Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) value chain, such as expertise, design, prototyping, experimentation, engineering, and pilot manufacturing, with further guidance to manufacturing in Europe.

*Training and Upskilling:* Opportunities for both technology- and application-specific learning using lecture-based tutorials and hands-on lab-based training within the hub's competence centers and extended to virtual classrooms.

*Business Support Services:* Including IP advice, business coaching, and support to find investment from venture capital and other public and private regional and European sources of innovation funding.

*Seamless Links to the Wider Ecosystem:* Targeted value-adding opportunities in the wider innovation ecosystem across all European regions, cluster organizations, and digital hub networks.

*Regional Collaboration & Sustainability:* The Growth Engine will include major "lighthouse" innovation hubs located in European regions with existing smart specialization strategies in photonics. These partners are committed to collaborating on the establishment of an exemplary innovation ecosystem of regional photonics innovation hubs tightly integrated with the Growth Engine. This will provide most European companies with local proximity to regional innovation hubs as their first point of contact, with seamless fast-track access to the European hub for cross-border support when needed. The goal of the regional hubs is to leverage local and regional resources for maximum impact on business growth within their regions, and to roll out this model to all European regions for the development of new innovation hubs. This activity will involve working with the NCP network across all EU member states, as well as existing regional networks such as European Regions Research and Innovation Network (ERRIN)[1]and Assembly of European Regions (AER)[2], to ensure sustainability through regional co-funding initiatives under the framework of Digital Europe.

*Integration with the Wider Innovation Ecosystem:* The Growth Engine will collaborate closely with established pan-European networks in the innovation ecosystem, such as the Enterprise Europe Network (EEN)[3] and the European Business Network (EBN)[4], to connect with companies, particularly SMEs in non-photonics industry domains. It will also work with the European Photonics Industry Consortium (EPIC)[5] for business development with European

1. https://errin.eu/
2. https://aer.eu/
3. https://een.ec.europa.eu/
4. https://www.ebn.lt/
5. https://epic-photonics.com/

photonics companies and linking with the manufacturing supply chain for photonics production in Europe. Additionally, the Growth Engine will engage with entrepreneurs, corporate investors, and venture capital firms through TechTour[1] to accelerate the development of high-potential startups and scale-ups in Europe. The Growth Engine will ensure alignment with other European, national, and regional initiatives and cluster organizations for the digitization of industry, providing access to other key digital technologies suited to cross-fertilization with photonics in a multidisciplinary innovation approach.

*Leveraging Finland's Expertise:* By leveraging Finland's existing expertise and infrastructure, including VTT, UEF, TAU, and oulu, the National Photonics Growth Engine will elevate Finland's capabilities to offer nationally significant expertise to other European partners. This will attract investments to Finland, making it an attractive country for research, development, and manufacturing. The foundation of this initiative will be the successful PREIN Flagship Program and the previously prepared photonics pilot line, creating a robust ecosystem for photonics innovation.

*Business Finland Growth Engine Program:* This initiative aligns with the Business Finland Growth Engine Program[2], which aims to create business ecosystems targeting over €1 billion in new business. These ecosystems are implemented through a partnership model involving companies, research organizations, and public actors, aiming to address global market disruptions and create new growth sectors in Finland. Business Finland has funded growth engines through capital loans and grants (orchestration funding). Although the funding for new growth engines has been temporarily halted, ongoing projects related to existing growth engines will continue to receive support.

## Workforce Growth and Development

**Objective:** To enhance and expand the workforce in the photonics sector through comprehensive education and training programs, ensuring a steady supply of skilled professionals to meet the industry's growing demands - Europe's most competent photonics community.

**Background and Justification:** The rapid growth of photonics research and development activities in Finland highlights the need for a highly educated workforce with advanced knowledge and technical skills. A recent survey from the national industry has highlighted the need for 5000 new professionals in the next five years in the sector. This imperative emphasizes the strategic significance of investing in the education and development of doctoral students in photonics-related fields. Photonics education in Finland is already at a reasonably good level, with several universities offering specialized programs. University of Eastern Finland (UEF) launched a Master's and Doctoral program in photonics in the fall of 2023. Similar programs are available at Tampere University and Aalto University. Additionally, a nationwide education specifically designed for industry utilization, the I-Deep doctoral program, is launched in 2024 with innovative approaches to teaching that accelerate graduation time without compromising the quality of education. However, cater to the needs set by the national industry, it is crucial to further develop and expand photonics educational initiatives in Finland.

**Actions:**

**Enhancing University Education:** Strengthen existing photonics programs at UEF, TAU, and aalto.
Introduce new courses and specializations to keep up with the latest advancements in photonics technology.

**Pilot Programs for Engineering and Secondary Education:** Launch pilot projects for engineering and secondary education in photonics. These programs are essential to ensure a continuous flow of skilled technicians and engineers.

**Collaboration and Networking:** Start with a pilot project in Joensuu, involving UEF, Karelia University of Applied Sciences, and Riveria Vocational School. Expand the pilot to the Helsinki Metropolitan Area, Tampere, and Oulu.

1. https://techtour.com/
2. https://www.businessfinland.fi/en/for-finnish-customers/services/funding/growth-engines

**Continuous Learning and Professional Development:**

*Lifelong Learning:* Develop programs for continuous learning and professional development to help current professionals update their skills and stay competitive.

*Workshops and Seminars:* Organize regular workshops, seminars, and training sessions focused on the latest photonics technologies and applications.

*Phased Implementation:* Begin with the pilot project in Joensuu, leveraging the collaboration between UEF, Karelia[1], and Riveria[2]. Gradually expand the pilot to other key regions, including the Helsinki Metropolitan Area, Tampere, and Oulu, to create a nationwide network of photonics education and training centers.

**Expected Outcomes:**

**Increased Workforce:** A significant increase in the number of skilled professionals in the photonics sector.

**Skilled Workforce:** Improved skill levels among current and future photonics professionals, ensuring they are equipped with the latest knowledge and techniques.

**Regional Development:** Strengthened regional capabilities in photonics, contributing to local economic growth and innovation.

**Industry Collaboration:** Enhanced collaboration between educational institutions and the photonics industry, leading to more industry-relevant training and research.

By implementing these actions, we can ensure that Finland remains at the forefront of photonics innovation and maintains a competitive edge in the global market. This comprehensive approach to workforce growth and development will support the long-term sustainability and success of the photonics sector in Finland.

## Enhancing Finland's International Influence and Export in Photonics

**Objective:** To enhance Finland's international influence and trade in the photonics sector by establishing closer bilateral relationships, promoting dual-use products, increasing international visibility, and leveraging EU funding.

**Background and Justification:** Strengthening Finland's international influence and trade is crucial for the growth and sustainability of the photonics sector. By building closer relationships with key countries, promoting dual-use products, increasing visibility on the global stage, and effectively utilizing EU funding, Finland can enhance its competitive edge and drive economic growth.

In the National Photonics Survey 2023 companies report that the biggest assistance they would need to facilitate their growth is on finding international partnerships. Also, expanding expertise in export regulation is in the top ten needs Finnish companies report.

**Actions:**

**Establishing Closer Bilateral Relationships:**

*Target Countries:* Focus on establishing closer bilateral relationships with Germany, France, and the USA. These countries are leaders in photonics and related technologies, and stronger ties can lead to increased collaboration and trade opportunities.

*Collaborative Projects:* Initiate joint research and development projects, exchange programs, and industry partnerships with these countries to foster innovation and knowledge sharing.

**Promoting Dual-Use Products:**

*Definition and Scope:* Identify and promote photonics products that have dual-use applications, meaning they can be used for both civilian and military purposes.

*Regulatory Compliance:* Ensure that these products comply with international regulations and standards for dual-use goods.

*Market Expansion:* Develop strategies to market these dual-use products to both civilian and defense sectors globally.

**Increasing International Visibility:**

*Global Presence:* Participate in international conferences, trade shows, and exhibitions to

1. https://www.karelia.fi/en/frontpage/
2. https://riveria.fi/

showcase Finland's photonics capabilities and innovations.

*Marketing Campaigns:* Launch targeted marketing campaigns to highlight Finland's strengths in photonics and attract international partners and investors.

*Thought Leadership:* Publish research papers, case studies, and success stories in leading international journals and platforms to establish Finland as a thought leader in photonics.

**Securing Funding:**

*Leveraging EU Funding Opportunities:* Actively seek and apply for EU funding opportunities, such as Horizon Europe, to support research, development, and innovation in photonics.

*Consortium Building:* Form consortia with other European countries and institutions to increase the chances of securing EU funding and to foster cross-border collaboration.

*Project Management:* Develop robust project management capabilities to effectively manage and execute EU-funded projects, ensuring compliance with funding requirements and maximizing impact.

**Expected Outcomes:**

**Market Expansion**: Increased market share for Finnish dual-use photonics products in both civilian and defense sectors.

**Global Recognition**: Greater international visibility and recognition of Finland's photonics capabilities, attracting more partners and investors.

**Increased Funding**: Successful acquisition and effective utilization of EU funding to support photonics research, development, and innovation.

**Enhanced Collaboration**: Stronger bilateral relationships with Germany, France, and the USA, leading to increased collaboration and trade in the photonics sector.

By implementing these actions, Finland can significantly enhance its international influence and trade in the photonics sector, driving economic growth and innovation. This comprehensive approach will ensure that Finland remains a key player in the global photonics landscape.

## Strengthening the Photonics Ecosystem

**Objective:** To further strengthen and sustain the well-developed Finnish Photonics ecosystem and maximize it's current and future impact.

**Background and Justification:** According to the Finnish National Photonics Survey 2023 the national photonics industry has 300 companies and employs 6000 people. Photonics studies and research are present at universities, universities of applied sciences and to some degree at vocational college. Research institutes are active in Photonics research and the Research Council of Finland has awarded a Flagship Program for Photonics. Together they form the existing Finnish National Photonics Ecosystem, and they have been actively brought together over the past 10 years by Photonics Finland. The active functioning of this community is demonstrated by multiple common national and international activities coordinated by Photonics Finland. Every year the Finnish Photonics Ecosystem is represented at Photonics West, the largest international event in Photonics. Our national booth joins companies and educational institutions. In Europe the national booth is also present at Laser World of Photonics, the largest European event in Photonics. Nationally, an example of a growing ecosystem is cities join to boost innovation with Photonics being a key component to it. Photonics Finland also coordinates activities with the national unemployment agency and photonics companies to upskill job seekers in photonics.

Global competition and rapid changes make it a necessity for companies to invest in the development of new kinds of products, services and solutions, better digital capabilities and an improved understanding of the market and customer needs. Finland's government is committed to the national target of increasing Finland's research and development expenditure to 4% of GDP by 2030[1]. Also, the Finnish

1. https://www.treasuryfinland.fi/investor-relations/sustainability-and-finnish-government-bonds/the-national-plan-to-raise-rd-funding/

government recognizes platforms and ecosystems of various sectors as crucial for innovation activities[1]. Ecosystems are interdependent networks between enterprises, entrepreneurs, researchers, public administration and third-sector operators. They are a means to solving broad-based and complex problems in society that need expertise from several sectors. A national photonic ecosystem is needed to facilitate cooperation, co-creation and piloting photonics solutions between different sized enterprises, education providers, research institutes, third-sector operators, public administration and end users. Moreover, photonics is a key to enabling technology to make it possible for other technologies and application areas to grow. It will therefore enable key sectors such as quantum computing, microelectronics, circular economy and many more.

Photonics Finland coordinates the Finnish Photonics Ecosystem activities already and has received a BRONZE Label Certificate for Cluster Management Excellence[2]. To get to the next level of support and cater to the needs of the growing ecosystem more resources are needed. Also, the execution of the other five action recommendations and keep the general growth of Photonics in Finland requires sustainable and stable coordination activities.

**Actions:**

**Securing a Leading Company Program in Photonics:** Photonics as key enabling technology provides solutions to global megatrends and challenges. The Phonics industry has expressed interest in leading programs that would tackle such challenges. Securing a Veturi program for Photonics is needed to facilitate these activities.

**Internationals presence**: The Finnish Photonics Ecosystem is already present in Europe and the US. Expansion of activities is needed to other parts of the work, for example Japan.

**Secure Funding:** Ensure sufficient funding for the operations of ecosystem coordination. Estimated costs of yearly coordination operations are €0.5 million.

**Expected Outcomes:**

**Economic Growth:** Increasing the national R&D expenditure by doubling the Finnish Photonics Industry by 2030. In practice this means increasing the Photonics Industry revenue from 2 billion to €4 billion and increasing the number of employees from 6 000 to 12 000 by 2030.

**Global and national recognition:** Finland is a forerunner in collaborative photonics research, technology development, and innovation. Finland has one of the leading photonics ecosystems in Europe.

**Enhanced National Collaboration:** Increased number of R&D projects and collaboration initiatives between industry, academia and domains of photonics applications.

1. https://tem.fi/en/ecosystems
2. https://www.photonics.fi/2024/03/28/photonics-finland-have-been-awarded-with-the-bronze-label-recognition-of-the-european-commission-cluster-excellence-initiative/

# Ecosystem Buildup Approach

High-tech industries thrive on well-developed ecosystems that facilitate collaboration, knowledge exchange, and efficient technology transfer. In rapidly evolving fields, strong ecosystems help bridge the gap between research, industry, and policy, accelerating innovation cycles and commercialization. These ecosystems enhance resilience, attract investment, and position nations at the forefront of global technological advancements.

**International Best Practices**

Successful ecosystems worldwide, such as Germany's Photonics21[1], the Netherlands' PhotonDelta[2], and the United States' AIM Photonics[3], showcase how coordinated efforts between research institutions, industry players, and policymakers drive innovation and economic growth. Finland can leverage insights from these models to enhance its photonics ecosystem.

**The Finnish Photonics Ecosystem: Domestic Impact**

Finland's photonics ecosystem serves multiple stakeholders, and entities like Photonics Finland and PREIN form an internationally significant hub. Additionally, collaboration between cities is crucial to enhancing the ecosystem's reach and impact. This effort has begun through the national leadership of Innocities[4], and its continuation should be secured.

**Key Areas of Focus:**

- **Research-to-Research Collaboration:** Strengthening partnerships between universities and research institutes enhances knowledge sharing and drives the development of groundbreaking technologies.
- **Research-to-Industry Partnerships:** Facilitating direct engagement between researchers and companies accelerates the commercialization of innovations, fostering new business opportunities.
- **Research-to-Public Sector Synergy:** The public sector must stay informed about the evolving needs for maintaining competitiveness. Key actors, Research council of Finland, Business Finland, and the ministries need to receive up-to-date knowledge to align public funding and policy support.
- **Industry-to-Public Sector Cooperation:** Enabling the integration of photonics in critical national infrastructure, such as security, telecommunications, and energy management, strengthens national resilience. This ensures public funding is directed effectively and contributes to Finland's 4% R&D investment target.
- **Photonics and Application Areas:** Strengthening cross-sectoral connections ensures that photonics innovations are seamlessly integrated into industries like telecommunications, manufacturing, healthcare, and defense, with particular focus on semiconductor and quantum technologies.

**International Engagement and Collaboration**

Finland's photonics ecosystem plays a vital role in global advancements through:

- **Participation in EU Consortia:** Engaging in Horizon Europe and Photonics21 initiatives provides collaboration opportunities and access to funding to grow local and EU ecosystem capabilities.
- **Bilateral and Multilateral Partnerships:** Strengthening ties with leading photonics research centers and industries worldwide fosters knowledge exchange and innovation.
- **Technology Export and Knowledge Sharing:** Promoting Finnish photonics innovations globally through trade missions, conferences, and industry partnerships raises Finland's profile in the international market.

By focusing on these strategic areas, Finland can further solidify its position as a leader in photonics innovation, contributing to the global advancement of photonics technologies.

1. https://www.photonics21.org/
2. https://www.photondelta.com/
3. https://www.aimphotonics.com/
4. https://innokaupungit.fi/en/photonics/

# Executive Summary

Finland fosters a dynamic and rapidly evolving photonics ecosystem, yet its full potential remains untapped. With targeted actions, Finland's photonics industry is on a track to reach €4 billion by 2030, driving breakthroughs, for example, in quantum technology, high-performance computing, and XR technologies. Photonics is a key enabling technology, forming the backbone of innovation in AI, dual-use applications, and medical technologies. Without photonics, key technological advancements—such as autonomous systems, medical imaging, and precision manufacturing—would not be possible.

Photonics has been identified as a key area in Finland's **Semiconductor Industry Roadmap**, highlighting its potential to drive innovation and economic growth. The Finnish National Photonics Roadmap 2025–2030 is designed to realize this potential, ensuring that Finland strengthens its role as a European leader in photonics and translates innovation into economic success.

Key Objectives:
• **Strengthen R&D and Innovation** – Increase investment in photonics research to secure Finland's technological edge with dedicated Research Council of Finland and Business Finland funding programs.
• **Industrial Growth** – Expand the Finnish photonics market to €4 billion by 2030, leveraging rapid global demand.
• **Workforce Development** – Build a strong talent pipeline through specialized education and training.
• **Sustainability & Green Transition** – Utilize photonics for energy-efficient manufacturing, smart sensing, and climate monitoring.
• **International Leadership** – Position Finland as a forerunner in global photonics collaborations and markets.

Strategic Actions:

1. **Increased Funding & Infrastructure** – Secure national and EU investments to develop cutting-edge research facilities and innovation clusters.
2. **Accelerated Commercialization** – Strengthen support for startups, scale-ups, and industry-academia collaboration to bring innovation to market.
3. **Education & Talent Attraction** – Establish world-class training programs to meet industry demand and globally attract top experts.
4. **Policy & Regulatory Support** – Shape policies that incentivize photonics adoption across strategic sectors.
5. **Global Expansion** – Deepen international partnerships to drive market access and innovation leadership.

Expected Impact:
• A thriving photonics industry reaching €4 billion by 2030, cementing Finland's global position.
• High-value job creation and retention in cutting-edge industries.
• A resilient and sustainable industrial base, accelerating Finland's green transition.

Photonics is an essential part of Finland's ambition to allocate 4% of GDP to R&D and innovation, securing national competitiveness in the global high-tech economy. To realize this vision, Finland must act now. The recommendations outlined in this roadmap should be swiftly implemented to ensure Finland remains at the forefront of photonics-driven innovation and industrial success. This also strengthens collaboration opportunities, including funding and technology partnerships within the EU, further integrating Finland into the European innovation ecosystem.