PHOTONICS21

Position Paper

Investing in Light: The Vision to Secure Europe's Competitiveness in the Global Tech Race

European photonics industry calls for a bold public-private investment initiative to empower Europe's critical strategic and defence sectors.

Executive Summary

This position paper urges the European Commission to launch a stand-alone programme for photonics, with a ring-fenced budget of at least €2 billion in the 2028-2034 Multiannual Financial Framework (MFF), to leverage €6-8 billion, in line with industry's €200 billion pledge. Photonics is vital to 20% of the EU economy, and drives innovation in manufacturing, defence, healthcare, and energy. It is equally essential to some of today's most advanced technologies in artificial intelligence, robotics, quantum, and semiconductor chips – all of which rely on photonics at their core. Yet, Europe risks losing its edge to China and the United States, where billions are invested annually. With over 50% of EU photonics firms reliant on Chinese components, this stand-alone programme is critical to secure supply chains, scale manufacturing, and ensure technological sovereignty. Swift action is needed to reinforce Europe's global leadership in this fast-growing sector.

Calls to Action:

- Establish a €2 billion stand-alone programme for photonics in the 2028-2034 MFF to drive €6-8 billion in industrial co-investment in photonics R&I in Europe.
- Launch a new class of Photonics Grand Challenge Proposals that will give Europe a competitive edge in geopolitically sensitive domains such as AI, space, manufacturing, health, agrifood, quantum, and defence.
- Accelerate photonics manufacturing scale-up in Europe to secure supply chains for critical industries.
- Create high-TRL photonics application hubs to accelerate technology transfer in key European sectors.
- Raise the investment readiness of photonics firms to turn start-ups into global industry leaders.
- Ensure a strategic role for (Integrated) Photonics in the Chips JU 2.0.

This initiative is a clarion call for the European Commission to act decisively. By investing in photonics, Europe can safeguard its industrial base, strengthen its defence capabilities, and lead the world in a technology shaping the future. The time to secure Europe's photonics advantage is now.

1. Europe's opportunity to lead the world in photonics: the most essential technology of the 21st century

Harnessing the power of light is vital to innovation and growth across the entire economy, from energy to agriculture. Industry across the world is now accelerating its use of photonics in all markets to deliver competitiveness, driving the photonics industry to continue to grow at 6.8% annually, five times the rate of the rest of the European economy[1]. It encompasses almost 5,000 SMEs[2] and 572 start-ups, positioning Europe as a leading and highly dynamic region. The European Commission described Photonics as underpinning 20% of the economy back in 2012[3]. This dependency is increasing as the latest developments in most European industry sectors, such as manufacturing, agri-food, health, ICT, defence, aerospace and automotive, are all built on and with photonics. The pervasive impact of photonics is now globally recognised. It has attracted international competitors, with the United States and China investing billions annually in photonics R&D to achieve global dominance[4,5]. China's rapid

[1] Photonics Market Study 2024 – Highlights & Trends, Tematys/Photonics21, 2024.

[2] See ibid., p. 34.

[3] The Leverage Effect of Photonics Technologies: The European Perspective, Directorate-General for the Information Society and Media (European Commission), 2012.

[4] Analysis of US Grants for Photonics R&D Funding, Tematys/Photonics21, 2024.

[5] Political Steering Processes in China in Core Segments of the Photonics Industry, EAC International Consulting, 2024.

advancements in photonics and aggressive industrial policies threaten to outpace Europe, pushing our industries into a position of dependency. Over 50% of EU photonics companies rely on components from China, exposing a dangerous vulnerability[6].

Despite these competitive threats, **photonics is one of the few deep-tech sectors where Europe excels**, and the EU has been especially successful in innovating in and producing high-end (often lower volume) optical systems. Lithography and metrology equipment for the semiconductor industry, optical systems for (aero)space and defence applications, healthcare equipment and smart manufacturing are all examples of Europe's strengths in photonics.

As photonics applications continue to expand and demand increases, we are now at a turning point. The increasing pace of technology change means that by 2040, many of the industries dependent on photonics will be using technologies yet to be invented. With competitive levels of investment, we can build on European strength, meet that demand from Europe, delivering economic growth and increasing supply chain resilience with European-innovated and manufactured photonics.

For photonics domains such as solar cells, displays and low cost, high volume optical components such as LEDs and optical fibers where, from an economic perspective, Europe is not currently in a leading position globally, it is necessary to at least secure knowledge and a minimum level of manufacturing capability in Europe for future robustness of industry and society.

This strategic investment in photonics will be essential to ensuring Europe's technological sovereignty in a rapidly changing world. Without it, **key industries** — ranging from semiconductor manufacturing and defence to secure communications and artificial intelligence — will be at risk. Geopolitical tensions, increasing global protectionism, and the **weaponisation of supply chains** have exposed Europe's reliance on foreign photonics providers, highlighting the urgent need for a robust European photonics ecosystem and the opportunity for increased European growth.

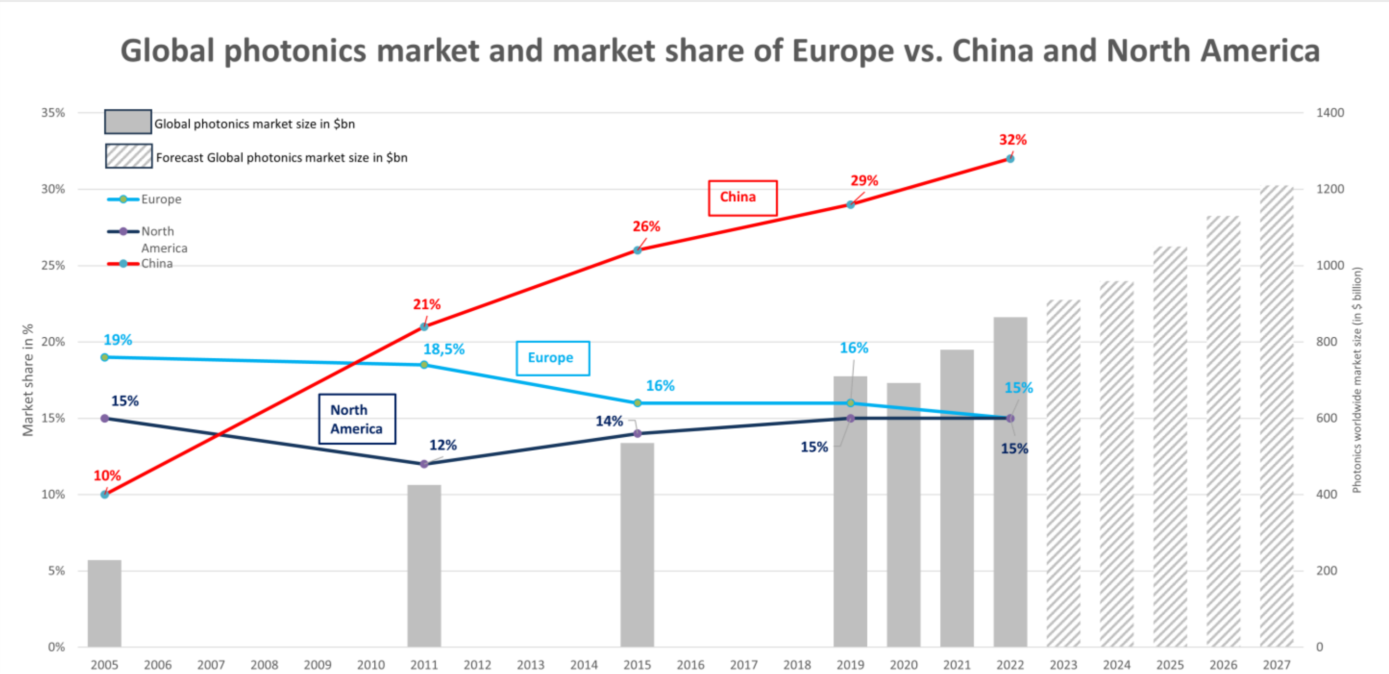

Figure 1: Global photonics market development over time and market share of Europe vs. China and North America. Data and Forecasts: Photonics21/Tematys, Photonics21 Market study, 2024.

[6] Photonics Industry Supply Chain Survey 2023, Photonics21/EPIC, 2024.

2. Photonics: lighting everything, adding value across industries

Creating light, transmitting and manipulating it, having light interact with the world and sensing that interaction are the roots of how photonics adds value. The diversity of these processes and the different forms of light are why photonics has such a broad impact.

Photonics is embedded in everyday life and high-tech industries alike. From high-power lasers that cut, mark and join metals and exotic materials together in manufacturing cars and batteries to the optical fibres that transmit all the worlds data; from cameras and laser range finders guiding autonomous vehicles, missiles, and spacecraft to the microscopes detecting cancer and telescopes exploring the universe; from photovoltaic cells converting sunlight into energy to LED efficiently illuminating our homes, streets and factories. **Photonics is all around us, impacting everyone, everywhere.**

In all of these applications, photonics adds value, not through a single property or component, but through its combination into a system. This added value is particularly true in Europe, where our expertise in combining photonics components is key to delivering competitiveness. For example, while the **European integrated photonics sector** is expanding rapidly, it currently **accounts for just around 20%** ($186 bn) of the total European photonics industry. This sector is being funded under the current EU Chips Joint Undertaking (Chips JU) through pilot lines, design tools and manufacturing. The **majority of value creation**, **namely 80%** ($728.5 bn)[7], is driven by photonic technologies that may build on integrated photonics or employ technologies that are separate from integrated photonics. We also need strategic investment in the non-integrated photonics sector to secure an economically resilient photonics industry.

Future advances in photonics will come from both superior components and improved combinations. The interconnected nature of light-based technologies means that improvements in one area can drive progress across multiple applications. The advantages to be gained will not be realised by focusing innovation solely on single applications or component platforms. Advances in chip-level photonics, supported by the EU Chips Act, will be crucial. However, their full value will only be realised when combined with innovations in other components, such as freeform optics, highly advanced fibres, metamaterials, extreme light sources, and system-level manufacturing innovation.

The cross-cutting nature of photonics underpinning diverse applications means it is substantially more efficient and lower risk to support innovation through a dedicated **stand-alone programme for photonics**. Only through this policy, and with significant investment in photonics, will advances in efficiency, manufacturability, and durability be adopted across multiple industry sectors and markets. Strategic supply chain resilience and industry competitiveness will be delivered across various supply markets, ensuring long-term **economic resilience** and **strategic autonomy**.

3. Photonics Innovation underpins Critical European Industries and Defence:

To achieve the next step in photonics-enabled innovation, highly challenging innovations in core photonics platform technologies are needed from the community of photonics experts. In this context, specific core technologies will not only have a dual-use but a multi-use character, in which the benefits of the development of such key technologies can be spread to a large number of application areas. A significant improvement in one core photonics component, for example, a tenfold increase in the power of ultra-high-power lasers, will open the door to new possibilities in manufacturing processes, long-range defence, elimination of space debris and compressed fuel for inertial fusion. Other core technologies, such as high-power single photon sources, will enable new opportunities for diagnostics for preventative healthcare, improved food security, secure communication and precise collection of metrology data. In the figure below, it can be seen how a similar innovation multiplier can be achieved through innovations in the core photonics components of large-scale free space optics, high-speed optical detectors, new laser-generated wavelengths, optical fibres, efficient optical interconnects, integrated photonics (PIC) and metamaterials (see Figure 2).

In this way, core photonics components and technologies have a significant impact on key European challenges such as secure communication, energy and food supply, defence, efficient optics-based data processing, environmental control, healthcare and independence in strategic technologies as described in the Grand Challenge proposals. The Grand Challenges proposals form the core of a much-needed, bold EU investment initiative in the field of photonics.

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[7] "PICs in Photonics Components". Tematys, 2025. Unpublished source.

Figure 2: Photonic technologies are critical for European defence and strategic industry capabilities.

4. Calls to Action: A bold EU investment initiative on photonics is needed

The upcoming Multiannual Financial Framework 2028-34 (MFF) is a unique opportunity to strengthen Europe's industrial and defence capabilities, drive economic growth, and globally lead in all the critical industries that depend on photonics. Europe must stop punching below its weight and rise to the challenge of competing with global powers. To secure its place on the world stage, Europe needs to provide the photonics industry and SMEs – many of which are hidden champions in their respective fields – with a level playing field.

By investing in photonics innovation, Europe can secure its technological autonomy and deliver cutting-edge photonics solutions to its critical strategic and defence industries – ensuring resilience, competitiveness, and long-term leadership in this essential sector.

A €2 billion stand-alone programme for photonics for the next MFF

The EU should establish a dedicated programme for photonics in the EU's next Multiannual Financial Framework (MFF) (2028–2034) with at least **€2 billion** in public funding. This will leverage at least four times this level of investment from the private sector, delivering a total programme of **€6–€8 billion**. The programme will directly tackle Europe's long-standing gap in time to market, bridging the disconnection between world-class research and commercial deployment by addressing eight key **Grand Challenge Proposals** identified by industry as critical to accelerating the transformation of next-generation photonics into the products and solutions vital for leadership in the 21st century.

Photonics Grand Challenge Proposals: A European Response to the Global Technology Power Shift

To secure global leadership in critical technologies, the EU must launch a new class of **Photonics Grand Challenge Proposals,** which are outlined in detail in the annex. These **bold initiatives** will give Europe a competitive edge in geopolitically sensitive domains such as **AI, space, manufacturing, health, agrifood, quantum, and defence**. Each Photonics Grand Challenge Proposal will:

- Address mission-critical European priorities, including digital sovereignty, climate-neutral infrastructure, automated defence systems, and secure communications.
- Establish and underpin European capabilities in strategic domains where long-term reliance on non-European technology poses systemic risks.
- Span the full innovation pipeline, from frontier research and prototyping through piloting, industrialisation, and large-scale deployment.
- Target breakthrough innovation in key photonic technologies and their applications, such as photonic computing, quantum photonics, and extreme-light systems.
- Deliver real-world, market-ready products and solutions by the end of the 2028–2034 Multiannual Financial Framework (MFF).

As ambitious rallying endeavours, these Grand Challenges will mobilise Europe's research, industrial, public sector, and financial communities around the following clearly defined strategic objectives.

- Lightspeed AI: Powering Europe's Next Generation AI Infrastructure with Light
- The Zero Contaminant Challenge: Next-gen Photonics Deep-tech for Clean Food and Environment
- Ensuring Clean Orbit and Europe's Defence Security with Directed Photonic Energy
- Personalised Optical Digital Twin: Photonic Health Monitoring for Europe's Preventive and Precision Medicine
- Directed Energy Effectors and Photonic Integrated Circuits for Defence: Innovations for Sovereignty
- Scaling Photonics Innovation and Investment for European Industry: The Test-before-Invest Grand Challenge
- Microfactories for Space and Defence
- NextGen Photonics: Unlocking New Horizons Through Secondary Sources

The Photonics Grand Challenges Proposals will foster dual-use innovation and promote synergies between civil and defence sectors, ensuring that Europe remains globally competitive while safeguarding its autonomy.

Each Photonics Grand Challenge Proposal will require a **public investment of €250–900 million** from the MFF. This investment will be **matched by at least a fourfold contribution from the European industry** through co-investments in R&D, pilot lines, manufacturing capacity, and deployment infrastructure – representing a powerful public-private leverage model.

To deliver on the Photonics Grand Challenges and secure resilience in the global photonics-enabled markets, the next MFF must also support scale-up and innovation in core photonics technologies, raise investment readiness of European photonics, ensure comprehensive coverage of photonics in the EU Chips JU 2.0 and break silos in the photonics-enabled markets.

Stimulate continued innovation in core photonics technologies

To ensure the next generations of core photonics components will emerge from the European photonics community by setting and investing in technology objectives which, when achieved, will create a significant impact across a wide range of application areas. For this, virtual development centres for selected core components should be set up to bring together the European photonic expert community. In this development, the centre's basic results in photonics innovations will be brought from the TRL-level of 2 to core components with a TRL-level of up to 6, ready for the next steps in industrialisation.

Substantial Raise in Investment Readiness of European Photonics and Photonics-Enabled Companies

By implementing the above measures, Europe steps up its game to turbocharge the investment readiness of its photonics firms and photonics-enabled companies to compete globally. The programme will lead the charge, guiding scale-ups with heavy-hitting support from initiatives like the European Innovation Council “EIC STEP Scale Up scheme”. Through targeted funding, mentorship, prototype/process validation and market access, the programme aims to transform promising start-ups into global players, ensuring Europe’s photonics sector does not just compete but dominates.
The additional and timely focus on manufacturing, investment and supply chains, beyond previous frameworks, drives the need for a significant increase in budget due to the cost of automation, validations of new materials and processes, especially against imported incumbent alternatives. They have the substantial benefit of focusing on anchoring manufacturing in Europe.

Ensuring a Strategic Role for Integrated Photonics in the Chips JU 2.0

Whilst Europe must develop platforms that enable the rapid scale-up of photonics across areas such as high-power single-photon sources, ultra-high power laser systems, large-scale free-space optics, high-speed optical detectors and new laser-generated wavelengths, integrated photonics is, by design, already aligned with the wafer-scale techniques of the semiconductor industry. This makes it essential that the integrated photonics sub-domain is incorporated into the EU Chips JU 2.0. Photonics21 should play an active role in the governance of the future Chips JU 2.0 under the next Multiannual Financial Framework (MFF). This includes contributing strategic input – particularly to the road mapping process – to ensure that integrated photonics is firmly positioned as a dedicated investment priority. To support this goal, Photonics21 will prepare a proposal outlining how integrated photonics can be more strategically reflected in the Chips JU’s Electronic Components and Systems Strategic Research and Innovation Agenda (ECS SRIA).

Speed is Sovereignty: Accelerating Photonics Innovation for Europe’s Edge

Speed is a strategic necessity. To meet the urgent demands of Europe’s defence and critical industries, photonics innovation must move from lab to market much faster. In today’s volatile global landscape, delays risk deepening Europe’s reliance on non-European technologies, weakening both industrial resilience and strategic autonomy. International competitors, such as the U.S. and China, are advancing rapidly through bold, coordinated, and well-funded photonics programmes. Europe must match this ambition with equal urgency. We call on the European Commission to embed speed as a foundational principle in future R&I frameworks. This means streamlining administrative processes, enabling mechanisms for rapid-response calls to emerging challenges, reducing time-to-grant, and fast-tracking high-impact, dual-use projects. To accelerate deployment, clear targets must be set for advancing Technology Readiness Levels (TRL) and Manufacturing Readiness Levels (MRL), supported by agile, industry-led pilot lines and scalable demonstrators.

Break the Silos: Let Photonics Power Europe’s Industrial Future

A new mindset is needed in designing the next EU Research and Innovation Framework. Deep technologies like photonics must be empowered – by design – to collaborate across all end-user sectors, including defence, space, health, energy, and digital infrastructure. Current siloed instruments in Horizon Europe make joint funding with diverse sectors nearly impossible. We call on the European Commission to enable flexible, cross-cutting collaboration models that reflect how photonics truly operates: horizontally, across markets. Removing structural barriers will unleash its full impact, accelerate dual-use innovation, and ensure Europe leads in strategic technological domains.

Annex

Photonics21 Grand Challenge Proposal for the next MFF/FP10

Lightspeed AI: Powering Europe's Next Generation AI Infrastructure with Light

Situation Analysis

Artificial intelligence (AI) has the potential to reshape the European economy significantly. While the biggest AI service providers are headquartered outside Europe, a few contenders have appeared within Europe. They process exabytes of data over privately owned interconnected infrastructures, using Terabit-class optical links for interconnecting hundreds of thousands of distributed servers processing information across data centres.

The tremendous growth of AI data traffic, about 100% per year, causes severe scalability challenges. Some data centres already have their own dedicated power plant; the largest announced to date (in South Korea) exceeds 3GW. Making this growth sustainable will require a massive use of energy-efficient photonic technologies, not only for interconnects but also for data processing.

Vision and Goal: Europe's Window to Lead the Future of AI Hardware

Medium-sized data centres dedicated to AI can alleviate the power load and cope with real estate constraints in Europe. Used for training or inference, they will replicate models and data in clusters located hundreds or thousands of kilometres away. In addition, smaller data centres will perform inference locally at the edge. This will lead to a new distributed digital infrastructure for AI, where: 1) the communication infrastructure owned by traditional telco operators could be leveraged; 2) each company-specific customisation of the AI experience could be managed, and 3) sovereignty constraints on data storage could be met[8].

By exploiting the distributed nature of the computing and communication infrastructure in Europe, current EU gaps in developing an AI infrastructure can be turned into strengths. Rather than investing in new big and power-hungry data centres, the huge computational load required by AI could be distributed among small or medium-sized data centres connected by the capillary communication network already existing in Europe, encompassing terrestrial, mobile and satellite networks. This will also enhance the resilience of the whole infrastructure, since in a distributed infrastructure, computing load and traffic can be reassigned if a node or a link is broken. However, realising this vision of an adaptive, distributed, European network of data centres for AI will require significant technological challenges to be addressed.

While AI service providers need to scale up in Europe to better compete with the hyperscalers, Europe can take advantage of the leading position of the network and system vendors headquartered in the EU, e.g. Nokia and Ericsson, for terrestrial optical networks and ASN for undersea optical networks. As suppliers to all major cloud providers for their AI infrastructures, they are in a unique position to support the growth of AI at scale. The business opportunities, and their positive impact on new jobs, are huge, considering that as much as 90% of the growth in traffic in fibre networks is driven by AI. Keeping up with this trend requires a big scale-up effort. As an example, over the period 2022 to 2030, Cignal AI predicts that AI will call for a 6.2x increase in optical transceivers, with coherent optics for terrestrial and submarine interconnections more than doubling from 0.9 to 2.2M units, and short-reach optics inside data centres exploding from 4 to 26M units.

In the future digital infrastructure for AI, photonic technologies are expected not only to perform high-speed interconnects but also to become an integral part of the high-performance computation engines needed for AI tasks. Hereafter, we will refer to photonic computing technologies as comprising all photonic technologies necessary for the future AI digital infrastructure. Examples of these technologies are: ultra-high capacity and energy efficient optical interconnects based on integrated optical transceivers; energy-efficient optical switches, especially suitable for quasi-static and massive AI data flows; space-efficient intra-data centre optical interconnections, for example based on multi-core fibres; wavelength division multiplexing or optical layers in printed circuit boards (PCB); and optical co-processors, e.g. working as neuromorphic neural networks, to help GPUs and CPUs in specific tasks that require low latency and low energy consumption.

The limitations of today's electronic chips in speed, energy efficiency and scalability make the adoption of photonic computing technologies even more urgent. These technologies offer Europe a once-in-a-generation opportunity to lead the next paradigm shift in AI and high-performance computing (HPC).

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[8] EU regulations force the hyperscalers to develop their infrastructure in Europe to keep EU data and EU large language models in Europe.

LightSpeed AI will develop and industrialise sovereign, ultra-efficient, AI-optimised photonic processors capable of exascale performance. This breakthrough will enable a new generation of sustainable data centres, autonomous systems and secure, defence-grade computing, while reducing energy consumption and boosting performance beyond what silicon electronics can offer.
By harnessing photons instead of electrons, photonic processors can execute AI training and inference up to 50× faster and with 30× greater energy efficiency than today's electronic chips. This will enable Europe to handle surging AI workloads whilst dramatically lowering power demands, thereby aligning with both digital and climate objectives.
Through LightSpeed AI, Europe will:

- Develop and deploy next-generation energy-saving photonic processors with co-packaged optics and heterogeneous Integration, for AI and HPC.
- Build a full-stack European capability, from research labs and pilot lines to industrial-scale fabs and deployment.
- Create a new photonic AI ecosystem, by connecting AI hyperscalers with the full value chain, including materials and component developers, equipment manufacturers, network operators and service providers.
- Secure digital sovereignty by establishing a home-grown, dual-use technology platform for civil and defence computing.

Key Technological Challenges:
Developing photonic computing at scale presents several challenges. Integrating photonic components (lasers, modulators, waveguides, detectors) on to chips with high density and yield is non-trivial, since photons have larger wavelengths than electrons and require innovative nanofabrication techniques. Interfacing photonic and electronic systems is critical, since electronic I/O speeds can limit hybrid setups, whilst limiting insertion loss and distortion needs careful design. The integration of different functions (e.g. light generation, routing and data processing) in a single photonic chip requires the integration of different materials (e.g. silicon photonics, III-V materials, lithium niobate on insulator, and graphene or other 2D materials), as well as new designs. Achieving general-purpose programmability in photonic processors (for example, reconfigurable photonic circuits for AI algorithms) is another challenge. Scaling production to industrial volumes will require the establishing (and coordination) of photonic semiconductor pilot lines and supply chains in Europe, since photonic integrated circuits are a relatively small but strategic segment of the global chip market. Additionally, efficient data sharing will be enabled by new low-latency, high-speed transmission links using new fibres having a transmission bandwidth well beyond the established C- and L-bands, as well as by spatial multiplexing capability (e.g. multi-core fibres).
Beyond these physical layer aspects, communication and computing protocol stacks should be developed that ensure security and reliability in a distributed and integrated communication and computing infrastructure. AI will also require self-evolving networks that are capable of learning and anticipating user needs, self-generated digital twins, and novel techniques to make latency-sensitive decisions in new distributed AI architectures.

Key R&D tracks:

- Photonic Neural Processors: designing optical neural network accelerators (e.g. analogue optical matrix processors for deep learning inference), based on interferometers, resonators, or diffractive optics to perform ultra-low latency matrix multiplications for AI.
- Hybrid Photonic-Electronic Architectures: developing co-packaged photonic and electronic chips, where ultra-high capacity (tens of Terabit/s), energy-efficient (some picojoule/bit) optical interconnects replace electrical wires for chip-to-chip and intra-chip communication, eliminating bandwidth and heat constraints. This involves research on optical memory interfaces and integration with existing computing infrastructure.
- High-Speed Optical Interconnects: developing all-optical switches and packet-optical switches as a single system-on-chip, and removing the energy overhead of electrical signals by means of new system architectures where signals are processed in the optical domain whenever possible.
- Coping with 100% CAGR of AI workload: expanding petabit/s fibre networking, accounting for the specificities of large language models, and organising the efficient exchange, synchronisation and back-up of data in a distributed DC configuration. Examples of enabling photonic technologies are multi-band, multi-core and hollow-core fibre systems.
- Raising security levels to AI workload standards in the communications infrastructure by means of augmented optical resilience, optical sensing for self-monitoring, optical cryptography and sabotage-proof technologies.
- Materials and Fabrication:
    - Advancing photonic fabrication processes (e.g. using lithium niobate (TFLN), InP or silicon

nitride) to enable densely integrated photonic circuits. Developments will include new laser sources, on-chip, efficient modulators, and on-chip detectors operating at high speed and low power.
  - Nonlinear Optics (NLO) for Reinforcement Learning: developing and integrating ultra-fast non-linear optical (NLO) components to enable real-time, hardware-accelerated adaptive learning and on-chip feedback loops.
  - Developing ultra-high speed low-latency transmission systems based on ultra-low loss optical fibres over a large wavelength interval, hollow-core fibres with low transmission latency, and new optical amplifiers and active fibres beyond the already established C- and L-bands.
- Algorithms and Software: developing software toolchains and programming models for photonic computing, to be used by researchers and industry for AI and HPC tasks. This entails photonics-aware AI algorithms and compilers that can efficiently map computation tasks to optical hardware.

Economic, Societal, and Defence Impact:
Photonic computing promises game-changing improvements in performance and energy efficiency. Recent developments indicate that photonic chips can achieve up to a 30-fold improvement in energy efficiency and a 50-fold speed boost in AI processing. Such gains would greatly reduce the carbon footprint of Europe's data centres and supercomputers, which will be a critical benefit as AI-driven workloads surge. Europe's data centre power consumption is projected to almost triple to 150 TWh, representing approximately 5% of European power consumption by 2030 due to AI growth.[1] Mastering photonic AI hardware would create a high-value industry, reducing reliance on foreign chipmakers and capturing a significant share of the burgeoning AI accelerator market. It would spur innovation in sectors reliant on AI, from autonomous vehicles to biomedical research, helping to create jobs in these sectors. More energy-efficient data centres will align with Europe's climate goals, while enabling new AI-driven services. In the defence realm, photonic computing could be deployed for cryptanalysis, secure communications, and real-time AI, giving European defence agencies sovereign capabilities in critical computations.

Partners and Stakeholders:
A programme of this scope would involve a coalition of photonics experts, chip manufacturers, system integrators and end-users across Europe. Potential partners include RTOs like IMEC, TNO, ICFO, VTT, Fraunhofer and CEA-Leti (with expertise in photonic integrated circuits), industrial players such as STMicroelectronics, XFAB, Ligentec, Smart Photonics and others for semiconductor manufacturing, and companies such as Ericsson and Nokia for optical networking, cloud systems and system integration. European photonic computing startups such as Q.ANT (Germany) and LightOn (France) would contribute with cutting-edge optical processor designs. Supercomputing centres (Barcelona Supercomputing Centre, Jülich in Germany, etc.) and the EuroHPC Joint Undertaking, along with planned Gigafactories for AI, could serve as testbeds for photonic accelerators in HPC. End-user industries, including cloud providers and telecom systems operators, could integrate the technology to improve their AI services. By uniting these stakeholders, Europe can build a complete innovation ecosystem, from labs to fabs to application deployment, to exploit photonic computing for exascale AI.

Recommendations for Public Action and Investment
To realise the full potential of the *LightSpeed AI* grand challenge, substantial public investment will be essential to overcome the high-risk, high-capital barriers. The required funding must support the entire innovation value chain, ensure European technological sovereignty, and de-risk private sector engagement at critical stages (TRL 5 to TRL 9). The estimated public investment required over a 10-year timeframe is €500–650 million, allocated across the following key pillars:

1. **R&D (€170–200 million)**
   Includes funding of applied research, photonic computing architecture design, algorithms, system-level integration for high-throughput AI workload, extreme trustworthiness, capability for self-monitoring and reconfiguration (performance optimisation and security), new fibres, amplifiers and PICs, co-packaging technology, and early demonstrators. These activities will include academic-industry consortia, technology validation in labs, and software development.
2. **Industrial Pilot Lines and Manufacturing Scale-Up (€230–300 million)**
   Includes investments in:
   - Dedicated industrial photonic integrated circuit pilot lines (e.g. silicon, InP, lithium niobate), in close alignment with existing Pilot lines (e.g. PIXEurope).
   - Speciality fibre drawing and optical component manufacturing facilities.
   - Packaging and assembly testbeds, advanced wafer-scale prototyping, reliability and equipment integration.
   - Process qualification (TRL 6–7), yield optimisation, and foundry support.

- Establishing or expanding "first-of-a-kind" manufacturing infrastructure aligned with the EU Chips Act.

3. **Innovation Ecosystem and Exploitation (€70–100 million)**
   To support:
   - Startups and SMEs via acceleration programmes, vouchers, and de-risking of pilot production.
   - IP protection, licensing, and open technology transfer platforms.
   - Interoperability and standardisation efforts (hardware, components and software APIs) across the whole supply chain, in order to avoid fragmentation.
   - Pre-commercial procurement and early demonstrator deployments in data centres and HPC systems.
4. **Skills, Training, and Coordination (€30–50 million)**
   - Industrial and academic training programmes for photonics engineers and system designers.
   - Support for interdisciplinary PhD and postdoc programmes.
   - Coordination actions across Europe to harmonise efforts and manage large-scale consortia.

Expected Outcome
This scale of investment reflects the strategic importance of securing leadership in photonic computing as a dual-use European technology, critical to sovereignty and underpinning vital infrastructure. Importantly, public investment would be structured to leverage significant private co-funding, particularly during pilot manufacturing and commercialisation stages, targeting a 1:4 public-private leverage ratio over the full life cycle of the programme. With €500–650 million of public investment, *LightSpeed AI* would catalyse a transformative European capability in energy-efficient, AI-optimised photonic computing, anchoring a new generation of sovereign, green, and secure digital infrastructure.

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[1] "Photonic processor could enable ultrafast AI computations with extreme energy efficiency" MIT News, https://news.mit.edu/2024/photonic-processor-could-enable-ultrafast-ai-computations-1202

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Photonics21 Grand Challenge Proposal for the next MFF/FP10

The Zero Contaminant Challenge: Next-gen Photonics Deep-tech for Clean Food and Environment

Vision and Goal: towards a safe environment, food and human health

The agrifood industry has been subject to strong digitalisation and technological advances during the past few decades, including the introduction of the Internet of Things (IoT), smart machinery, machine vision inspection systems, and precision farming. However, continuous technological developments remain indispensable to offer healthy, nutritious and safe food for all. Current **key challenges** are the **reduction of food waste**, the **assurance of safe food and feed**, and the **minimisation of the use of resources and pesticides**, contributing to a safe environment and benefitting human health. Tackling these challenges is of major importance to cope with the growing world population, expected to grow to 10 billion people by 2050, and to build resilience to the ongoing climate change.

Around one-third of the world's food is lost or wasted along the food chain, of which the consumption stage contributes to 54% of the food waste. In the EU, over 59 million tonnes of food are wasted annually (Eurostat, 2024), with an associated market value estimated at 132 billion euros. **Food waste has a huge environmental impact within the EU**, being responsible for 16% of the CO2 emissions, 12% of the water use, 16% of the land use, and 15% of marine eutrophication.

Food safety remains a challenge, as different contaminants still sneak into the food chain, among others, pesticide residues, pathogenic microorganisms, and mycotoxins. Product recalls in the EU originate mainly from chemical contamination (45%), microbiological contamination (47%) and physical contamination (26%). In comparison, a smaller amount is due to an absent or incomplete labelling (26%), processing defect (13%) and the presence of unapproved ingredients (6%). From May 2024 to May 2025, over 5,800 food-related recalls were flagged across Europe. Food safety needs to be prioritised through inspections and good manufacturing practices. Today, the implementation of food safety programs is generally based on chemical analysis, which has a significant cost and therefore economic impact. At the same time, it leads to food losses due to the destructiveness of the analysis and induces chemical waste. Efforts should additionally be made towards **early disease detection**, both in agriculture and in health, reducing costs and treatment times.

Finally, a transition to a **sustainable and chemical-free agriculture** is indispensable, since agrifood accounts for 70% of the global water use and 24% of the greenhouse gas emissions. The excessive use of fertilisers and pesticides needs to be tackled, together with the need for **clean water** and **smart irrigation**. Currently, 60-70 % of EU soils are unhealthy. At the same time, an average amount of 61 kg/hectare of inorganic fertilisers is used on agricultural land across the EU (in 2022). Finally, the transition to ecological fuels, as biofuels from algae, needs to be extended and explored.

Key Technological Challenges

Photonics technologies play a crucial role in tackling the above challenges, offering a **non-destructive and chemical-free evaluation**. Ongoing developments towards novel optical sensors, imaging systems, smart labels, and lighting particularly benefit product monitoring. This **grand challenge aims to boost the technology further and to use photonics technologies as an enabling technology to offer an early intervention, diagnosis, and treatment**. More specifically, this involves addressing the following key technological challenges:

- Internet-of-plants: real-time plant health monitoring, while also enabling predictive farming (real-time non-invasive health, stress, pests, and nutrients monitoring).
- Autonomous farming involving autonomous robots that can identify and treat individual plants with precision, watering, feeding, or removing pests.
- Soil monitoring - minimising resources by dynamic precision fertilisation and irrigation.
- Vertical farming with light-driven growth control: Use smart lighting to control plant growth, morphology, and yield.
- Non-destructive multi-element and multi-contaminant food screening (quality, safety, nutrients).
- Full traceability from farm to fork, eliminating food fraud and ensuring safety.
- Emission monitoring towards reduced greenhouse gas emissions.
- Spectroscopy-at-Home, in-shop, and in the fridge.
- Water monitoring and disinfection along the food chain (irrigation water, wastewater, etc.).
- Non-invasive, low-cost diagnostics enabling early detection and suitable for regular screening.

In addition to the technology development, a strong focus should be given to the **miniaturisation** and **cost-reduction of the technologies**. To enhance the take-up of the technology, a cost vs value evaluation is indispensable, implying the need for exploration towards scaling and high-volume production.

Key R&D Tracks

New technological advances are required to address the above technological challenges, involving, but not limited to, the following technologies:

- Laser and light-based technologies for weed control, precision treatment
- Photonics barcoding using fluorescent nano-tags / light-activated smart packaging
- Efficient lighting for vertical farming
- Miniaturised low-cost multi-spectral / hyperspectral imaging
- Multimodal spectroscopic sensing and advanced sensor fusion
- Portable and implantable photonic sensors
- Flexible photonics circuits on leaves / distributed fiber sensing
- Air, water and soil pollution sensing
- Disinfection/water cleaning for micropollutant removal
- LIDAR for 3D mapping of fields and plants

To ensure a take-up of the technologies by the agrifood industry, a **cost-value optimisation** of these technologies is indispensable. In addition, a downscaling of the current high-level technologies is required, together with their upscaling using mass-manufacturing approaches, to pursue cost reduction while maintaining the system accuracy and robustness of the high-level systems.

For widespread adoption, the **miniaturisation** of the technologies, together with an enhanced versatility and adaptability of the systems deploying a multi-element multi-application approach, is a significant challenge.

Finally, the **integration of the developed technologies** needs to be tackled within existing workflows. It needs to be **optimised to be operational at a large scale outside of laboratory conditions.**

Economic, Societal and Technological Impact

A transformation is required towards a **safe and environmentally friendly EU food system**. **Photonics is a key enabling technology with the potential to revolutionise agrifood and health by reducing the need for chemicals, enhancing food safety and quality, reducing food waste and reducing greenhouse gas emissions, ensuring a signifi**cant societal and economic impact. Considering irrigation management, the use of soil moisture sensors and drip irrigation is expected to save 25-30% of water compared to traditional irrigation. Lighting control has the potential to increase yields by 10-20% using optimised light spectra. The use of IoT sensors and cameras for pest and disease detection is expected to enable a reduction in crop losses up to 40% by allowing an early intervention.

Photonics for the environment and photonics for agriculture and food are among the **fastest-growing photonics segments worldwide**. Photonics for Agriculture and Food is a strongly growing emerging market, with a CAGR of 11.8% (Tematys Market Research Study Photonics 2024). Europe has the expertise and technologies to take up technological leadership within the field.

To address this challenge, a **multinational and multi-technology approach** is required. The technological developments that will be achieved within this grand challenge will also **drive innovation and offer cross-application in health and manufacturing**. In the **defence fi**eld, these technologies will empower environmental and human safety by enabling the early-stage detection and action towards the presence of unwanted and harmful chemicals in water and air.

Links to and interdependencies with other essential technologies

Tackling this grand challenge requires a **multi-technology approach**, where the integration of photonics with other key technologies is crucial. This includes the use of AI and IoT, including also the generation of digital twins, robotics and automation, Chips JU for PICs, and biomedical engineering.

Partners and Stakeholders

Collaboration among **scientific institutions, industry stakeholders, regulatory bodies, and end-users** will be crucial to maintaining strong standards while promoting long-term enhancements. Stakeholders play an important role in gaining insight into the final application needs and therefore need to be involved at the early stage, including the involvement of the end-consumer, and in addition to industries and regulatory bodies.

Key research and technology organisations include AgriFOODTef, Wageningen University & Research, IRTA Institute of Agrifood Research and Technology. Industrial players include, among others, Specim, Bosch Sensortec / Bosch AgTech, BASF Xarvio, HySpex, Agrointelli, Ecorobotix, Vivent Biosignals, and Philips.

Alignment with European and Regional innovation hubs is required to align the infrastructure with local industrial needs.

Recommendations for Public Action and Investment
To overcome the technical risks and unlock industrial scalability, while enforcing Europe's leading position and maintaining the steep technological growth within the agrifood industry, a substantial public investment is required, allocated across the following key pillars:

1. **R&D (€170–200 million)**
   Funding of applied research, photonic computing architecture design, algorithms, system-level integration in agri-robots, drones, greenhouses, vertical farms, plants, and food processing companies, and early demonstrators. Includes academic-industry consortia, technology validation in labs, and software development.
2. **Photonics farm of the future: evaluation centres and technology hubs (€230–250 million)**
3. **Demonstration platform (€170–200 million)**
4. **Skills, Training, and Coordination (€30–50 million)**
   - Training programs for **photonics engineers and system designers**.
   - Support for **interdisciplinary PhD and postdoc programmes**.
   - Coordination actions across the EU27 to harmonise efforts and manage large-scale consortia.

Expected Outcomes
Strengthening food and environmental safety within the EU is a continuous challenge, impacting human health, requiring a **one-health approach**. **Closed-loop technological innovations, involving photonics sensing, digital twins, and actuation, are indispensable to address the entire production and distribution chain, up to the consumers at home**. The novel technological innovations are envisioned to contribute to the EU Soil Deal, the Farm to Fork Strategy, the End-of-Waste Directive initiative and to the United Nations Sustainable Development Goals, while empowering Europe's resilience towards climate change.

PHOTONICS21

Photonics21 Grand Challenge Proposal for the next MFF/FP10

Ensuring Clean Orbit and Europe's Defence Security with Directed Photonic Energy

Vision and Goal

Ultra-high power lasers with very high pulse energy in the kJ range and continuous wave lasers with multi-100 kW average power enable long-distance interaction with objects, even in the range of some 100 km. This property allows the manipulation and processing of any material over a long distance. Currently, ultra-high power lasers are available at power levels of 500 kW, and there seems to be no limit for power scaling in the MW range. That predestines ultra-high power laser systems as the ideal tool for directed energy for the use in defence against drones, ammunition and missiles in modern warfare and in cleaning up the orbit of space debris. With laser-based defence against drones the actual mismatch between drones and ballistic weapons can be overcome and an effective tool to fight against multiple drone attacks can be installed.

Therefore, the development of ultra-high power lasers and related photonic system components, such as large-scale adaptive mirrors and photonics-based sensing and targeting systems, is indispensable for the realisation of this space and airborne-related grand challenges.

The problem of space debris with more than 1 Mio particles and components > 1 mm in Low Earth Orbit (LEO) between 800 – 1000 km is rapidly evolving from a distant concern to an imminent threat to current and future space activities. As space becomes increasingly crowded with satellites - both active and decommissioned - the risks of collision, the generation of additional space debris and the potential for catastrophic events such as Kessler Syndrome are increasing exponentially. Immediate action is needed to ensure that space remains accessible for scientific, commercial and defence purposes. For this reason, Active Debris Removal (ADR) using photonic-based directed energy is essential to remove space debris, to clear up our orbit and to protect the increasing number of communication, navigation and weather satellites.

Similar to space debris removal, the defence of drones and missiles becomes increasingly important in the current geopolitical situation. Here, directed energy systems, like high-power lasers, provide a cost-effective and fast solution against direct hazards. European defence companies like Rheinmetall, MBDA, Thales, BAE Systems and others have prototype systems under development to protect Europe against foreign attacks. Both applications for ultra-high power lasers and photonics components have a huge impact on European national safety and future security in space-based communication, navigation and satellite-based environmental information.

Even if Active Debris Removal (ADR) is currently a development topic with a billion euros market size, it has huge potential in the future, which is essential to remove space debris, to clear up our orbit and to protect the increasing number of communication, navigation and weather satellites. Currently, ADR, together with the necessary detection strategies and components, will sum to a market size between 20-30 Bn$ within the next decade and will continue to increase with a CAGR of more than 10% as different market studies point out. Moreover, an OECD study says that quantifying the costs associated with space debris and the benefits of satellite activities presents a complex challenge. While economic impacts have been estimated at USD 191 billion at risk globally, societal implications, such as disrupted services and environmental damage, are harder to quantify but equally significant.

As described in a recent NASA report, laser-based removal of space debris will be the most successful and economic technology. So-called laser nudging can be performed in two different ways, either by irradiating the space debris part with a high average power continuous wave laser of more than 100 kW and using the photonic pressure, or by slightly vaporising part of the material of the space debris and generating a recoil pressure. For this approach, a high short-pulse energy laser with more than 10 kJ pulse energy is necessary. Both technologies will lead to the remediation of the orbit by slowing down the particles and subsequently re-entry into the atmosphere.

On the defence side, high-power laser systems, which are under development at several companies, currently have a market volume of $5 billion annually. With the strong growth of worldwide military expenses, it is estimated that the market will grow up to €35 bn within the next 10 years. European companies like Thales, IPG, Trumpf and Rheinmetall could profit significantly from this market increase. Moreover, high pulse energy lasers, which can be part of a space debris removal system, are necessary for future laser fusion systems. Here, the current market size of more than 50 Bn is estimated.

Key Technological Challenges
As described above, primarily ultra-high power lasers and/or ultra-high energy lasers are needed for versatile and effective space debris removal and directed energy systems. For long distance irradiation and fast missile following, large optical systems with automated tracking properties are necessary. For mobile applications compacts energy storage and supply devices are needed to integrate lasers and optics in ships, trains and trailers. Moreover, several range-finding and communication technologies are necessary for this approach. Even if the development of powerful laser systems and photonic-based sensor devices is the major task, the integration of space-related technologies like rockets and space-related control mechanisms is inevitable. Therefore, the support and mobilisation of different photonic and space-related stakeholders at the EU level will boost the important and long-lasting innovation on space debris removal.
The following key technological challenges have to be addressed in detail.

Key R&D Tracks
- High Power Lasers with cw-power of more than 50 KW (and high energy-efficiency if space-based) for continuous irradiation of space debris particles at altitudes of up to 1000 km, generation of sufficient photonic pressure to slow down the particle sufficiently for further re-entry into the atmosphere.
- High Short Pulse energy Lasers with energy levels of more than 10 kJ to achieve sufficient fluence for laser ablation and vaporisation to generate recoil pressure and sufficient propulsion at the particle
- High Power continuous wave Lasers with more than 500 KW for continuous irradiation of drones and missiles at altitudes of some km, together with photonic targeting and sensing technologies
- High-power eyesafe lasers for ensuring flight security in the use of laser-based directed energy systems in combination with fast tracking sensors
- Large-scale optical systems with adaptive beam quality control to compensate atmospheric disturbances such as scattering, refractive index local fluctuations and absorption.
- High-accuracy space debris and satellite sensing using long-distance LiDAR systems and multi-sensor optical approaches
- Intersatellite communication for fast control of laser manipulation and detection of small particles with mobile satellite-based sensor devices.
- Earth satellite communication for controlling remote sensor satellites and space-based laser systems
- Secure communication between the different active elements, which can be quantum-based.

For the realisation of a laser-based space debris removal and directed energy systems, a strong cooperation with other activities and technology developments is necessary. Here, links to and interdependencies with other essential technologies like micro-electronics, software, and quantum technologies are important.

Economic, Societal, and Defence Impact
Today, essential services such as telecommunications, navigation, weather forecasting, earth observation and security-related systems are already based on satellite-based platforms. The global market for satellite-based services alone amounted to over USD 400 billion in 2023, with double-digit percentage growth forecast - particularly due to the launch of large constellations such as Starlink, OneWeb and Amazon Kuiper.
Space debris removal is becoming increasingly important economically - not only as a risk reduction measure, but also as a future market in its own right. Technological solutions such as laser-based orbit modification, robotic gripper systems, or deorbit satellites are creating new potential for value creation. Initial European players such as ClearSpace, Astroscale and LeoLabs are already demonstrating the market interest and technological feasibility of corresponding services.
The increasing use of uncrewed aerial systems like drones, anti-ship missiles, and small boats necessitates a cost-effective countermeasure. Compared to a conventional missile system like Patriot, the cost of defending will be significantly lower and in the range of a few euros. The rapid growth in the military expenses of developed and evolving countries owing to the rising geopolitical tensions is accelerating the procurement of new land, air, and sea platforms. Europe has a strong ecosystem for high-power lasers, with companies like Trumpf, IPG, Thales, and others, and also powerful companies providing countermeasure systems like Rheinmetall, MBDA, and BAE Systems. With the cooperative development of these new defence systems, a Pan-European activity could be established instead of having single national solutions.

Required Actions and Public Investment
Actions needed to establish an innovation route from applied research in photonics up to industrial deployment,
1. **R&D&I (€170–200 million)**
   Funding of applied research, high power laser interaction research, high power laser set up evaluation and demonstration, system-level integration, and early demonstrators. Includes academic-industry consortia, technology validation in labs and early prototype developments.

2. **Evaluation centres and technology hubs (€230–250 million)**
   Large scale laser development centres with test devices for fast visualisation of interaction with different materials. Support centres for simulation of laser material interaction at ultra high power levels. Coordinated technology hubs for system integration including sensing, irradiation devices and materials analysis.
3. **Demonstration platform (€300–400 million)**
   Large scale, real world demonstration centres for missile and drone defence, evaluation platforms for fast space debris removal.
4. **Skills, Training, and Coordination (€30–50 million)**
   - Training programmes for **photonics engineers and system designers**.
   - Support for **interdisciplinary PhD and postdoc programmes**.
   - Coordination actions across the EU27 to harmonise efforts and manage large-scale consortia.

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Photonics21 Grand Challenge Proposal for the next MFF/FP10

Personalised Optical Digital Twin: Photonic Health Monitoring for Europe's Preventive and Precision Medicine

By Juergen Popp and Thomas Mayerhöfer (Leibniz Institute of Photonic Technology and Institute of Physical Chemistry, University of Jena, Germany)

Vision and Goal: A Paradigm Shift in Health Monitoring – from Reactive Treatment to Proactive Health Management

Europe's healthcare systems are under growing pressure: ageing populations, chronic diseases, pandemic threats, rising costs, and the demand for climate-resilient innovation. Long-term sustainable innovations call for a fundamental transformation. The solution lies in a health system that detects and halts disease *before* it emerges – **preventive, personalised, and technologically sovereign.**

Imagine such a system: a Personalised Optical Digital Twin (PODT) that creates a continuously updated, light-based digital representation of individual health – non-invasively, in real time, and with molecular precision. PODTs integrate information from biofluids (e.g., saliva, blood, urine) and tissues (e.g., skin, retina, mucosa), enabling dynamic health monitoring and precise medical insight. Complementary technologies such as electrical, acoustic or biochemical sensors add valuable physiological context – for example, heart rate variability, pH, or glucose levels. However, only photonics provides access to detailed molecular fingerprints deep inside the body without the need for invasive procedures. This unique capability makes photonics indispensable for capturing complex biological processes with the resolution, speed, and non-invasiveness required for personalised and preventive healthcare.

To realise this vision, many of the required photonic tools – from integrated laser systems to compact spectroscopic sensors and their AI-based interpretation – must still be invented. This innovation must come from within the photonics community, which offers the depth of expertise and infrastructure needed to achieve the necessary performance and integration.

Suppose we want to build a digital mirror of human health. In that case, only light can reflect, and only photonics can create the mirror.

The generated **multimodal data streams** are processed through AI-based modelling to simulate organ functions, immune responses, and disease trajectories in real time. This enables early detection, therapy monitoring, and targeted intervention – with individualised recommendations for both patients and healthcare providers.

A particular emphasis lies on the **detection and modelling of individual immune responses**. PODTs analyse molecular and physiological patterns – such as cytokine profiles, oxidative stress, or fever curves – enabling dynamic immunomonitoring in real time. This opens new pathways for **the early detection and personalised management of infections**, chronic inflammatory diseases, and immunotherapies. At the same time, PODTs contribute to pandemic preparedness, antimicrobial stewardship, and the implementation of the **European One Health strategy**.
The **Optical Digital Twin** is therefore more than just a technological innovation – it represents a new, resilience-oriented, future-proof vision for health in Europe.

Key Technological Challenges

Realising the PODT concept requires overcoming complex challenges across the entire innovation chain—from signal acquisition to clinical integration. A central task is the integration of multimodal biophotonic sensing technologies into compact, robust platforms based on photonic integrated circuits (PICs). These include Raman and infrared (IR) spectroscopy for molecular diagnostics; fluorescence lifetime imaging microscopy (FLIM) and optical coherence tomography (OCT) for tissue imaging; and surface-enhanced Raman scattering (SERS) and coherent anti-Stokes Raman scattering (CARS) for highly sensitive, label-free detection. These platforms must reliably detect early-stage inflammatory, infectious, metabolic, or neurodegenerative conditions across a variety of sample types, including saliva, sweat, blood, skin, retina, and mucosa, requiring optimised light–tissue interfaces and advanced miniaturisation.

Equally crucial is the integration of microelectronic and acoustic sensors (e.g., ECG, EEG, EMG, Ultrasound, temperature, pH, glucose) to provide physiological context including blood flow, vessel diameter, blood volume fraction, blood pressure, heart rate (HR), heart rate variability (HRV), oxy- gen saturation (SpO_2), and tissue oxygenation (StO_2). Fusing these heterogeneous data streams in real time into individualised, explainable AI-driven models will enable dynamic simulation of organ function, immune responses, and disease trajectories. However, ensuring the quality of unsupervised measurements remains a key challenge - especially for wearables and remote systems that may produce erroneous data despite MDR certification. Addressing this requires robust signal validation, sensor redundancy, and AI-driven plausibility checks to avoid false positives and build clinical trust.

To ensure sustainable deployment, devices such as wearables and lab-on-chip systems must be scalable, robust, energy-efficient, and interoperable. They must also meet EU standards for clinical validation, cybersecurity, and data protection, while remaining upgradeable and maintainable to guarantee long-term adaptability. Finally, human-centred, intuitive user interfaces are essential to ensure adoption, empower patients, and support clinicians with actionable, personalised insights.

Key R&D tracks
The Personalised Optical Digital Twin initiative focuses on six R&D pillars:

1. **Multimodal Biophotonic Sensing:** Development of compact platforms integrating Raman, IR, FLIM, OCT, photoacoustics, nonlinear optics (e.g., CARS, SRS), and PICs for non-invasive molecular diagnostics from biofluids and tissues.
2. **Photonic–Microelectronic Integration:** Wearable and lab-on-chip systems combining sensors, e.g., for ECG, HRV, SpO2, StO2, glucose, temperature, and motion with wireless data transfer and energy-efficient electronics.
3. **AI-Based Twin Modelling:** Advanced AI architectures that fuse multimodal data into individualised simulations of organ function and disease progression. Models support real-time updates, explainability, and integration with clinical records.
4. **Dynamic Feedback Interfaces:** User-friendly mobile and clinical interfaces that translate complex biosignatures into actionable insights, supporting both patient empowerment and clinical decision-making.
5. **Federated Data Infrastructures:** Open ontologies, interoperable APIs, and GDPR-compliant federated learning frameworks to ensure cross-border scalability and data sovereignty.
6. **Clinical Validation and Readiness:** Pilot deployments for key medical areas (e.g., neurodegeneration such as Alzheimer's, oncology including cancer diagnostics, cardiovascular diseases like heart failure, metabolic disorders such as diabetes, and infectious diseases) will generate evidence for safety, efficacy, and regulatory compliance under MDR/IVDR – paving the way for integration into health systems.

Economic, Societal, and Health Impact
The PODT initiative aims to transform European healthcare by shifting from reactive treatment to proactive, personalised prevention. Using integrated biophotonic, acoustic and microelectronic sensors, PODTs enable continuous, real-time monitoring for early detection and targeted intervention in diseases such as cancer, chronic and cardiovascular conditions, diabetes, and neurodegeneration. This improves outcomes, reduces overtreatment, and supports a more efficient, digitally enabled healthcare system. PODTs empower individuals through personalised feedback, fostering informed decision-making and improving health literacy - especially for those with chronic conditions. They also reduce healthcare burdens by enabling at-home care, early discharge, and remote monitoring, while enhancing access in underserved regions. On a public health level, anonymised data supports early detection of infectious and environmental threats, aligning with the EU's One Health strategy. Economically, PODTs tap into a global digital health market projected to exceed USD ~€900 bn by 2030, with AI-powered diagnostics expected to reach USD 5–6 billion. Europe currently represents approximately one-quarter of the global healthcare market, translating into significant potential for capturing substantial shares of these emerging digital health segments.

The initiative drives innovation in photonics, AI, and medical devices - supporting SMEs, creating high-skill jobs in technology and healthcare sectors, and opening new markets in digital health solutions. The initiative reinforces **Europe's technological sovereignty** and reduces dependence on non-European platforms, aligning with the **EU Chips Act**, **Digital Decade**, and **European Health Data Space** compared to global competitors like the U.S. NIH's centralised All of Us program or China's state-driven Healthy China 2030 initiative, the PODT initiative offers a distinctly decentralised, privacy-by-design approach rooted firmly in European ethical standards, emphasising transparency, data sovereignty, and user trust. In summary, PODTs lay the groundwork for a resilient, inclusive, and future-ready European health system and a globally competitive industrial base.

Partners and Stakeholders in Europe – From Labs to Lives
The PODT initiative brings together Europe's full innovation ecosystem - from foundational science to clinical impact. Success depends on a broad alliance of partners across the translational pathway. **Foundational research institutions** (e.g., Leibniz-IPHT, ICFO, IMEC, Helmholtz AI) provide expertise in photonics, microelectronics, and AI. **System integrators and industry** (e.g., Zeiss, Siemens Healthineers, Smart Photonics, Q.ANT) drive the development of PIC-based systems and prototype user-ready platforms by combining photonic and electronic components. **Clinical partners** (e.g., Charité, Inserm, Karolinska, ERNs, UKJ) ensure medical relevance and conduct validation studies across diverse use cases. **Regulatory and ethical bodies** (e.g., EMA, TÜV, ethics boards) guide compliance and certification. Finally, **societal stakeholders** - including EU policy bodies, national ministries, patient organisations, and outreach networks - support adoption, education, and equitable access. This pan-European alliance, uniquely combining research excellence, industrial innovation, and clinical validation, ensures rapid translation of PODTs from cutting-edge research into real-world healthcare solutions – a level of integration unmatched by competitors such as the U.S. or China.

Recommendations for Public Action and Investment
To unlock the full potential of the PODT, coordinated public investment is essential - supporting the entire pathway from R&D to clinical adoption. We propose allocating **€700–900 million over 10 years**, structured across five strategic pillars:

1. **Research and Technology Development (€200–250M):** Supports applied R&D in biophotonic sensing, photonic integrated circuits, microelectronics, and AI modelling; the integration of multi-modal systems; and early demonstrators for diseases like cancer, cardiovascular, neurodegeneration, and metabolic disorders (TRL 3–6).
2. **Pilot Manufacturing and Validation (€250–300M):** Funds pilot production lines for lab-on-chip, PIC-based, and wearable systems, miniaturisation, packaging, clinical-grade prototyping, and compliance testing (TRL 6–8), aligned with the EU Chips Act and Digital Europe programs.
3. **Clinical Integration (€120–150M):** Enables large-scale pilots across EU clinics, usability testing, surveillance infrastructure, and reimbursement pathways. Focus areas include oncology, degeneration, cardiovascular rehab, metabolic prevention, infectious disease, and environmental health resilience.
4. **Ecosystem & SMEs (€80–120M):** Boosts startup acceleration, open-source digital twin frameworks, standards for EHR and wearable interoperability, and technology transfer to create a thriving European innovation environment.
5. **Skills & Coordination (€40–60M):** Invests in interdisciplinary training, fellowships, EU policy alignment, and citizen engagement to build long-term human and institutional capacity.

This investment will drive public–private co-funding, accelerate innovation, and deliver clinically validated, scalable PODT systems across Europe, positioning European companies to lead in the fast-growing markets of preventive medicine, digital diagnostics, and health monitoring technologies.

Expected Outcome: Public–Private Leverage and Impact
The proposed public investment is expected to leverage a 4:1 ratio of private co-funding in system development, manufacturing scale-up, and health service integration – resulting in a total mobilised investment exceeding **€3 billion over a decade**. By catalysing industrial and clinical uptake of sovereign, AI-enabled, photonic health solutions, Europe can claim first-mover advantage in a critical and fast-growing sector, positioning itself to secure a significant share of the rapidly expanding European and global markets for digital health and precision medicine. This will allow the EU not only to secure strategic autonomy in health technologies but also to **export world-leading solutions**, particularly to ageing societies and developing economies. Ultimately, the PODT initiative will establish Europe as the global leader in next-generation, personalised health infrastructure - delivering tangible benefits for individuals, health systems, and the broader economy.

Photonics21 Grand Challenge Proposal for the next MFF/FP10

Directed Energy Effectors and Photonic Integrated Circuits for Defence: Innovations for Sovereignty

Description

Photonics technology is now applied to a huge range of fields, including telecommunications, security, sensing, and imaging. The Photonics domain enables the creation of unprecedented architectures and functions in classical and quantum information processing, sensing and communication systems, making it a crucial domain for defence capabilities.

Photonics Integrated Circuits (PIC) generate an even greater impact in terms of new functionalities and embeddedness. For defence systems, PICs provide a true paradigm change by allowing an overall cost reduction, SWaP improvement and easier implementation (interconnection down to board level, uncooled operation and ruggedness). PICs have already proven such gains in civilian applications, and rely on an EU Value Chain that is still to be consolidated. However, defence applications have specific requirements that are not optimally fulfilled by current PIC components, modules and systems originally coming from civilian applications.

This challenge aims at fostering the development of Photonics with performance and functionalities dedicated to defence applications. On one side, high-power lasers are key tools for Direct Energy Weapons, critical for the security and defence against drone attacks, and to clean orbits in space. On the other side, PICs are bound to become a transverse enabling technology addressing a wide application scope, particularly in the following major defence domains: sensing (from acoustics to electromagnetics, both RF and optronic), communications, high-speed processing and waveform generation (both analogue and digital), time and frequency references.

Specific Defence Challenges

The ambition is to federate and ramp up the research and development efforts in Europe, building on the achievements of previous projects carried out in the framework of European civilian programmes (H2020-ICT, Pilot Lines, Horizon Europe), specific defence-focused initiatives (EDA OB Studies and CatB projects), as well as national projects. The main benefit of developing high-power lasers at alternative wavelengths is to interact more efficiently with artificial threats and to enhance safety for humans. The major expected benefit of PICs for defence applications is their high embeddedness potential (e.g. in UAVs, USVs, UGVs) owing to an extremely reduced footprint. Other benefits include quasi-monolithic circuits well adapted to severe environments (vibration and temperature fluctuation resilience) in all types of defence platforms; extremely accurate generation and control of time/phase delays over a large range of operation for beam shaping/beam control in RF and optronic systems; integrated nonlinear optics for versatile laser sources (wavelength, frequency); electronics/photonics co-integration.

The scope of the present challenge is to develop dedicated lasers and PICs to demonstrate identified functions responding to the needs of all of the following domains:

- Optoelectronic and Optronic Systems, including Directed Energy Effector Systems
- Free Space Optical Communication Systems
- Navigation
- RF Systems

Optoelectronic and Optronic Systems

Advanced LiDARs (such as multi-channel, software-defined waveform), active imaging systems (such as polarisation sensitive, 3D, multi-spectral), fibre-based sensors (such as Distributed Acoustic Sensing), phase and polarisation control in front-end designs of Directed Energy Effectors (LDEW) and Directed Infrared Countermeasure (DIRCM) systems are intended to be further developed. The PIC-based functions to be addressed are optical beam steering / optical phased arrays, coherent beam combining, non-linear optics for wavelength conversion, frequency-tunable lasers, wavelength-tunable lasers, integrated interferometers, or I/Q balanced photodetection, to name a few.

Free Space Optical Communication Systems

Multiplatform covert/high bit rate communications, anti-jamming of optical UAV communication, embedded communications, clock synchronisation and distribution are targeted. The PIC-based functions to be addressed are beamforming, mitigation of atmospheric perturbations, spatial demultiplexing and coherent beam combining, MWIR nonlinear optics, and high-repetition-rate entangled photon sources for quantum communication.

Positioning, Navigation and Timing

Laser source interrogation circuit for resonant gyroscopes, highly integrated frequency/time references, and photonic chip for high precision cold atom-based Inertial Measurement Units are to be addressed. The functions of interest are PICs with co-integrated gas cells, non-linear optics for wavelength conversion, ultra-narrow linewidth lasers, integrated interferometers, micro-combs for optical frequency division, integrated OPLLs, high dynamic range switches and filters.

RF Systems (Radars, Electronic Warfare systems, RF communication)

Waveform generation, beam forming, RF local oscillator and distribution, and ultra-wideband AD/DA conversions are functions of RF systems to be addressed. The PICs-based building blocks of interest for this domain are analogue and digital transceivers, optically assisted ADCs, compact optically-assisted RF Beam Forming Networks, ultra-low Vpi/linearised modulators, and high extinction filters.
All these domains may benefit from specific developments of low-power processing functions, such as optical neuromorphic architecture-based PICs. Applications include high-speed target classification and waveform recognition.

The proposals should address the development of the functions above and building blocks through existing European integrated photonic platform capabilities. For specific cases driven by the demonstrators, new technological developments to address defence requirements may be covered, such as, but not restricted to:

- High-power lasers and amplifiers (>20 dBm) at specific wavelengths.
- New laser sources at particular wavelengths (quantum for defence) with frequency tuning capabilities
- New laser and amplifiers architectures based on rare earth ions implantation in/on passive PICs (SiN, AL_2O_3 on SiN).
- New nonlinear PIC platforms for advanced processing functions (Chalcogenides, BTO, GaP).
- Linearised RF modulator with high power handling (>20 dBm) and large bandwidth.
- High-performance balanced photodiodes.
- High speed (<1 µs), low power consumption (<100 µW for pi phase shift), low optical loss (<0.1 dB) phase shifters.
- Highly linear and high-efficiency photodiodes with high photocurrents (saturation power >15 dBm)
- Specific free-space to waveguide interfaces for optronics and Free-Space-Optics (e.g. multi-layer gratings, meta-surfaces and lenses) for improved light control.
- New and emerging modulation techniques, such as orbit angular momentum beams, for built-in secure communications.
- Octave-spanning combs for self-referencing ultralow phase noise oscillators.
- MWIR and LWIR circuits allowing integration of modulators and detectors.
- Single photon counting detectors for wavelengths above 1600nm for Lidar with improved penetration in scattering atmosphere and improved stealth.
- Progress on packaging, hybridisation and co-integration techniques (micro-transfer printing, flip-chip bonding, edge coupling, micro-optics, interposers) for efficient implementation of these combined building blocks in a complex functional circuit.
- Interfacing (electrical) blocks to a PIC, like transimpedance amplifiers, laser controlling circuits, timing and synchronisation circuits, biasing circuits, etc. and integrating them to make a system.
- Design methodologies and flows to streamline optics & electronics & thermal simulation domains from system level to component level, and to speed up time to market.

Targeted activities

For each technical area as referred to in the functional requirements, the proposals must include some or all of the following activities:

- Analysis of the technical feasibility, requirement specification, trade-offs and concept definition for dedicated defence operational use cases;
- Development of technology demonstrator systems for operational use cases and approaches among those specified in this text.
- Performance verification in a controlled environment relevant to defence.
- Technology maturation, Industrialisation and Supply Chain development.

Expected impact

- Embeddedness of RF, optronics and acoustics sensors on a large variety of defence platforms, including extremely SWAP-constrained uncrewed vehicles;
- Innovative and accurate optronics sensors (both passive and active), laser effectors (LDEW), DIRCM, imaging systems and free space optical communications systems operating in a defence context;

- Processing functions, close to or integrated in the sensors, exploiting inherent parallelism of photonics to improve performances in constrained environments, maintaining a low consumption (based, for instance, in analogue pre-processing, neuromorphic processing/computing, A.I. embedded frugal HW architectures).
- Innovative and high-performance RF systems with multi-functional capabilities covering Radar, Electronic Warfare (EW), and communication tasks with a single photonic-assisted core;
- Increased interoperability between a large range of platforms (in particular uncrewed vehicles), owing to the integration of high data rate, atmospheric perturbation resilient, free space optical communication links;
- Development of EU supply chains at the best level, able to warrant sovereignty for these specific enabling technologies, thanks to a deep understanding of defence constraints and specifications and thanks to the capability to address, at the same time, a large range of civilian applications (allowing development and viability of a production tool at reasonable cost).

Photonics21 Grand Challenge Proposal for the next MFF/FP10

Scaling Photonics Innovation and Investment for European Industry: The-Test-before-Invest Grand Challenge

Challenge and Mission

The Photonics Test-before-Invest Hub represents a pan-European flagship initiative designed to accelerate the journey from photonics feasibility to full industrial deployment. As a Grand Challenge, this initiative addresses the critical gap between prototype and production by offering European companies, across all industrial sectors, seamless access to world-class photonics expertise, advanced technology platforms, pilot lines, foundries, and venture support. By empowering startups, SMEs, and scale-ups with both technological and business support, the Hub will significantly de-risk innovation, foster cross-sector collaboration, and catalyse the widespread adoption of photonics-based technologies, components, and products. Its mission as a European deep tech growth engine, bridging the notorious "Valley of Death" between prototyping and commercial scaling, is clear: to ensure that cutting-edge photonics solutions are not only developed in Europe but also scaled and manufactured in Europe, for Europe. By tackling persistent bottlenecks in upscaling and market uptake, the Hub will reinforce Europe's technological sovereignty, industrial resilience, and global competitiveness – positioning photonics as a key enabler of Europe's green, digital, and secure future.

Current State, Impact, and Limitations of European Photonics Innovation Support

Current State: Over the past two decades, the Photonics21 partnership has laid a robust foundation for industry-driven research and innovation. At the forefront of these efforts stands *PhotonHub*, the flagship instrument of Photonics21, which facilitates streamlined access to photonics innovation support across the continent. PhotonHub integrates Europe's leading prototyping facilities, pilot lines, foundries, and testbeds, providing access to TRL 2–7 infrastructure, expert guidance, business acceleration, and venture-readiness services.

Current Impact: PhotonHub – building on the legacy of ACTPHAST 4.0 and ACTPHAST 4R – has become a recognised one-stop innovation gateway. It has successfully supported hundreds of companies, primarily SMEs and entrepreneurial researchers, in accelerating the deployment of photonics technologies in new products and processes. This has led to the creation of thousands of high-quality jobs, the generation of hundreds of millions of euros in new revenues, the launch of dozens of start-ups, and the attraction of substantial venture capital investments into European deep-tech ventures.

Current Limitations: Despite its proven success, PhotonHub's impact remains constrained by limitations in scaling capacity, access to funding at higher TRLs, and insufficient integration with broader European manufacturing ecosystems and enabling digital technologies. To unlock its full potential and deliver systemic, long-term impact, PhotonHub must evolve into a fully scaled *Photonics Test-before-Invest Hub* – a next-generation platform capable of supporting the entire innovation lifecycle from prototype to production, firmly anchored in Europe's industrial, technological, and investment landscape.

Essential Partner Ecosystem for the Photonics Test-before-Invest Hub

To successfully scale the current initiative into a fully operational *Photonics Test-before-Invest Hub* – and to maximise its economic and societal impact – a comprehensive, collaborative, and full-stack innovation ecosystem is essential. This ecosystem must unite a diverse range of strategic actors, each playing a vital role across the photonics innovation value chain:

- **Universities and Research & Technology Organisations (RTOs):** Provide access to cutting-edge technology platforms, facilities, pilot lines, and expert knowledge for early-stage R&D, feasibility studies, prototyping, and upscaling.
- **Industry Pilot Lines and Foundries:** Offer industrial-grade testbeds to de-risk the transition from prototype to scalable, production-ready solutions.
- **Manufacturing and Packaging Partners:** Enable the critical lab-to-fab transition by ensuring compatibility with European industrial manufacturing and packaging standards.
- **Large Enterprises and System Integrators:** Support industrial scaling, mass manufacturing readiness, and access to global markets.

- **Photonics Companies:** Design and manufacture in Europe the high-performance components required to produce photonics-based commercial products at scale.
- **Start-ups and SMEs from All Industry Sectors:** Act as agile innovation drivers, bringing disruptive technologies to market with speed and flexibility.
- **Entrepreneurial Researchers:** Serve as a dynamic source of spin-offs and start-ups, translating breakthrough photonics research into disruptive new products.
- **Financial Actors (Venture Capital, Public Funding Bodies):** Provide the capital and risk-sharing mechanisms needed to scale innovation and bridge the "Valley of Death."
- **European and Regional Innovation Hubs:** Align infrastructure and services with regional industrial strengths, talent pools, and smart specialisation strategies.

Together, these partners will form the backbone of a resilient, future-proof photonics innovation ecosystem – ensuring that Europe remains at the forefront of photonics-enabled industrial transformation.

From Strength to Scale: Evolving PhotonHub into a Fully Integrated Photonics Test-before-Invest Hub – Enhancing Capabilities, Expanding the Ecosystem, Amplifying Impact

To fully unlock the transformative potential of photonics innovation in Europe, targeted public-private interventions are needed to build on the success of PhotonHub and elevate it to the next level. These strategic actions go beyond the current state-of-the-art, reinforcing and scaling the existing infrastructure to bridge the gap from early adopter feasibility to mainstream industrial deployment.

Key priorities include:

- **Scale-Up Funding:** Introduce blended financing instruments – combining public and private capital – to support innovation at higher Technology Readiness Levels (TRL 5–7), where development costs typically range from €300,000 to €500,000 per company.
- **Investment Mobilisation:** Create dedicated mechanisms for European scale-ups to access multi-million-euro venture rounds from top European investors strategically aligned with the mission of the Hub and fully engaged in the identification and advancement of high-potential opportunities, thus enabling more rapid growth and greater global competitiveness in photonics innovation.
- **Infrastructure Upgrades:** Invest in advanced prototyping and upscaling platforms, with a focus on pilot lines that align with evolving industrial standards. Key priority areas include extreme and freeform optics, specialty optical fibres, optical light sources, and the assembly and integration of optics and photonics systems, since significant support has already been provided for pilot lines dedicated to Photonic Integrated Circuits (PICs) across various material systems – such as InP, Si/SiN, and TFLN – as well as for quantum technologies, through initiatives like the Chips Joint Undertaking and other EU programs and since continued investment for the latter technologies is anticipated under the upcoming FFP10 framework.
- **Industrial Engagement on Production Pathways:** Incentivise early engagement of European photonics manufacturers and system integrators to ensure R&D efforts are aligned with industrial scaling requirements and market demand – ensuring that production remains *in Europe, for Europe*.
- **Digital and Green Alignment:** Ensure that photonics infrastructures and innovation use cases are fully aligned with Europe's digital and green transitions. This includes delivering meaningful contributions to Europe's key industrial sectors – such as healthcare, mobility, energy, and manufacturing – as well as to strategic technology domains like Artificial Intelligence and Quantum Technologies. These efforts must support sustainability, energy efficiency, and Europe's digital and technological sovereignty.

Expected Impact of the Photonics Test-before-Invest Grand Challenge
Building on the successful track record of the PhotonHub initiative, the Photonics Test-before-Invest Grand Challenge – backed by a €250 million investment – aims to generate substantial economic impact during the upcoming Financial Framework Program 10. The initiative builds on PhotonHub's proven ability to mobilise private investment, having already facilitated over €350 million in venture capital for European photonics start-ups and SMEs from an initial €20 million in public funding. In this next phase, the focus will expand to include more early-stage start-ups while placing greater emphasis on supporting more rapid scale-up, targeting larger investment rounds and accelerating the commercialisation of photonics technologies across Europe based on greater levels of European manufacturing and production across key strategic value chains for European sovereignty.

The projected outcomes include:

- Sustaining Europe's 15% share of the rapidly expanding global photonics market, which is expected to reach €1,000 billion by 2027, while maintaining a 7% compound annual growth rate (CAGR) in the European photonics sector.
- Upgrading five optics and photonics pilot lines to cutting-edge, state-of-the-art facilities that complement existing pilot lines in Photonic Integrated Circuits (PICs) and Quantum technologies.
- Supporting the creation of 80 new start-ups driven by photonics innovation.
- Providing innovation support to 400 European SMEs across diverse industry sectors – 300 for prototyping and 100 for scaling.
- Creating 5,000 new high-tech jobs directly through scaling of start-ups and SMEs across Europe, and a further 20,000 new indirect jobs in European manufacturing and production through the supported supply chain.
- Attracting €2 billion in venture capital to accelerate the growth of start-ups and especially scale-ups.
- Generating €4 billion in new company revenues within five years of launching photonics-enhanced products.

Photonics21 Grand Challenge Proposal for the next MFF/FP10

Microfactories for Space and Defence

Vision and Goal: A Strategic Capability for In-Space Autonomy and Resilience
The future of space exploration, infrastructure, and security demands systems that are not only high-performance but also self-sufficient, reconfigurable, and resilient[9]. Europe faces an opportunity to lead the next paradigm shift in space operations by developing **in-space photonic microfactories** – compact, laser-enabled systems capable of fabricating and repairing critical components directly in orbit.
PhotonMicroFab will develop and industrialise **modular photonic micromanufacturing platforms** for integration aboard satellites, space stations, and future planetary outposts. These systems will enable autonomous production of mechanical, optical, and electronic parts in microgravity, significantly reducing launch dependency and enabling **mission adaptability, rapid response**, and **long-duration independence**.
By harnessing the power of **laser sintering, photonic diagnostics, and direct-write laser printing**, PhotonMicroFab offers a transformative shift: from pre-manufactured, Earth-reliant hardware to **self-sustaining space infrastructure** – supporting both civil and strategic needs.

Through PhotonMicroFab, Europe will:

- Develop in-orbit-capable photonic fabrication modules for additive manufacturing and on-demand repair.
- Establish a sovereign innovation base for orbital manufacturing, from lab-scale to deployment on orbital platforms and deep-space missions.
- Secure Europe's strategic autonomy by creating **dual-use fabrication infrastructure** to support both commercial exploration and defence readiness.

Key Technological Challenges
Developing photonic microfactories for space introduces novel engineering and operational challenges:

- **Miniaturisation and integration** of high-precision laser systems, optics, and motion control into compact, radiation-tolerant form factors.
- **In-situ process monitoring** via embedded optical diagnostics for autonomous quality assurance under microgravity conditions.
- **Material handling in vacuum** and microgravity for additive/subtractive processes involving metals, ceramics, polymers, and 2D materials.
- **Thermal and structural stability** of photonic systems exposed to harsh environmental conditions (vibration, thermal wear, cosmic radiation).
- **Secure, dual-use compatibility**, where the same platform may serve strategic objectives, including critical asset repair or adaptive sensor deployment.

Key R&D Tracks

- **Additive Manufacturing for Space**
  Development of laser sintering and laser-induced deposition systems for micro-scale part production, enabling in-orbit repair and modular construction.
- **Photonic Diagnostics and Process Autonomy**
  Real-time, in-situ monitoring systems using integrated optics to assess part integrity, dimensional tolerances, and thermal signatures during and after fabrication.
- **Radiation-Hardened, Miniaturised Laser Toolkits**
  Resilient photonic subsystems optimised for deployment in space habitats, satellites, and deep-space

[9] https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Space_Optoelectronics/Photonics

probes.

- **Hybrid Material Processing**
  Photonic multi-material processing techniques (e.g., metal/graphene/polymer combinations) for multifunctional structures and embedded optics.
- **Onboard Photonic IC and Optoelectronics Manufacturing**
  Fabrication of waveguides, optical interconnects, and components for quantum and classical communication systems directly in orbit.

Economic, Societal, and Defence Impact
PhotonMicroFab empowers a strategic shift in space infrastructure from pre-fabricated and Earth-dependent to **autonomous, serviceable, and reconfigurable**. The benefits span multiple domains:

- **Economic**: Reduces launch mass and costs through on-demand and digital orbital manufacturing with small non-recurring engineering time. Fosters high-value sectors in photonics, space logistics, and additive manufacturing.
- **Societal**: Enables sustainable space missions with lower environmental impact and minimisation of waste. Supports space-based climate monitoring and Earth observation with upgradable instruments.
- **Defence**: Enhances Europe's preparedness and autonomy in space. Photonic Microfactories can support rapid in-situ fabrication of mission-critical components, including optics for secure communication, sensor recalibration, or strategic asset repair.

By building a sovereign, dual-use platform for in-space production, PhotonMicroFab aligns with Europe's digital, space, and security policy ambitions – fostering resilient and independent orbital operations.

Partners and Stakeholders
PhotonMicroFab will bring together leaders across photonics, space systems, and autonomous manufacturing:

- **Research & Technology Organisations**: Fraunhofer ILT, TNO Space, ICFO, CEA-Leti, and The Aerospace Corporation (via collaboration) for core laser systems, diagnostics, and microgravity manufacturing research.
- **Industrial Players**: Airbus Defence & Space, OHB SE, Thales Alenia Space for systems integration and in-orbit platform deployment.
- **Photonics Manufacturers**: Trumpf Photonics, Nanoscribe/BICO, Ligentec for space-qualified photonic tools and subsystems.
- **Startups & SMEs**: Space manufacturing startups for 2D materials, hybrid fabrication, and onboard instrumentation.
- **Strategic Enablers**: ESA, EDA and national defence entities for infrastructure access, security alignment, and operational scenarios.

Together, they will form a European innovation ecosystem, spanning TRLs 3–9, capable of delivering the next generation of space-based photonic micro-factories.

Recommendations for Public Action and Investment
Realising PhotonMicroFab's full potential will require targeted public investment to overcome early-stage technical risks, unlock industrial scalability, and position Europe as a leader in orbital manufacturing. Estimated investment over 10 years: **€450–600 million**, with a 1:3 leverage from private co-funding.

1. **R&D and Demonstrators (€150–170 million)**
   Support fundamental research, system design, early prototype validation, and mission-preparatory testing.
2. **Industrial Pilot Lines and Space Qualification (€180–220 million)**
   Establish photonic fabrication pilot lines, environmental testing facilities, and integration testbeds (e.g., at ESA's ESEC or ISS/Bartolomeo platforms).

3. **Ecosystem Development and Dual-Use Acceleration (€80–100 million)**
   Support SME and startup participation, IP strategy, open interfaces, and strategic deployment in civil and dual-use demonstration missions.

4. **Skills, Training, and Strategic Coordination (€30–50 million)**
   Develop interdisciplinary curricula in space photonics, hands-on testing platforms, and alignment with defence and civil space innovation programs.

Expected Outcome
PhotonMicroFab will catalyse a sovereign European capability in space-based photonic and digital manufacturing, enabling on-demand fabrication, resilience, and sustainable exploration. This will be dual-use infrastructure and will strengthen Europe's strategic posture.

PHOTONICS21

Photonics21 Grand Challenge Proposal for the next MFF/FP10

“NextGen Photonics”: Unlocking New Horizons Through Secondary Sources

Vision and Goal: Secondary Sources as a technology leap
Secondary sources hold the potential to unlock transformative advancements across numerous technologies. One prominent example is the generation of extreme-ultraviolet light, which has revolutionised chip manufacturing processes and positioned Europe as a global leader in the production of lithography tools. This breakthrough has also enabled the widespread adoption of artificial intelligence, further solidifying Europe's role in technological innovation. Beyond chip manufacturing, secondary sources are paving the way for new applications by leveraging high-energy particles such as electrons, neutrons, ions, or x-rays. These groundbreaking possibilities are expanding rapidly, broadening the scope of industries that can benefit from this cutting-edge technology.
Imagine the widespread availability of table-top synchrotron-like sources for radiation therapy (electrons, protons). This would revolutionise specific cancer treatment in hospitals worldwide. Likewise, such X-ray and neutron sources would enable high-speed scanning of containers at unmatched accuracy and transparency in transport and worldwide logistics. Another premier example is ongoing investigations into the analysis of closed nuclear waste barrels using high-energy neutron sources. Laser-driven secondary sources are the only way to enable these demanding applications.
The overarching goal of this initiative is not only to explore these emerging applications but also to industrialise and establish robust manufacturing capabilities for secondary sources within Europe. By doing so, Europe seeks to strengthen its technological sovereignty, ensuring that access to these advancements is secure and that their production remains local. Building a cohesive ecosystem, spanning research and development laboratories to full-scale industrial deployment, will be central to achieving this vision. The focus on secondary sources as a technological leap promises to enhance Europe's competitiveness and drive innovation across sectors ranging from battery production to semiconductor manufacturing.

Through NextGen Photonics, Europe will:
- Discover new fields of applications for secondary sources
- Build a European ecosystem – from R&D labs to industry deployment
- Strengthen Europe’s technological sovereignty by ensuring access to and manufacturing capabilities for secondary source applications.

Key Technological Challenges
Developing industry-grade secondary sources and designing useful applications entails several challenges. First, laser systems have to be developed satisfying the high technological requirements with regard to, e.g. pulse duration, energy efficiency, high repetition rates and temporal stability. Second, target materials need to be designed to withstand the high-intensity laser pulses. This includes effective debris management. Third, for industrialisation, such systems need to be miniaturised and integrated into existing production lines. Finally, these systems need to provide sufficient versatility and adaptability to satisfy application-specific requirements in different applications, ranging from battery production to semiconductor manufacturing.

Key R&D tracks
- Laser development: Development of ultrashort-pulsed solid-state laser systems satisfying the high technological requirements. This includes pulse durations from ns to fs and other specific parameters such as pulse powers, wavelengths, brilliance, or temporal stability, depending on the particular applications.
- Target development: Laser-driven secondary sources require target systems that can operate under high-intensity laser pulses. Managing debris generated during the interaction between the laser and the target material is a critical challenge. Effective debris mitigation strategies are necessary to protect sensitive components and ensure long-term operation.
- System integration and miniaturisation: For widespread adoption, secondary sources need to be integrated into existing workflows and be operational outside of laboratory conditions. This involves developing compact and robust systems without limiting performance.
- Deployment: Developing versatile and adaptable systems that can meet the diverse needs of potential future applications is a significant challenge. Different applications, such as treatment in a hospital

environment, quality assurance in battery production, semiconductor manufacturing, and material research, have specific requirements for secondary sources. Therefore, fundamentally developed systems need to be fine-tuned to match these requirements.

Economic, Societal, and Defence Impact
The development and industrialisation of secondary sources promise significant economic, societal, and defence impacts in the future. Economically, these technologies will drive innovation across various sectors, including health, EUV-lithography for semiconductor manufacturing, battery production, and material research, by providing high-brilliance and high-resolution imaging and analytical capabilities. This will enhance quality assurance processes, reduce production costs, and create new market opportunities. Likewise, it will ensure Europe's economic sovereignty in these strategically highly relevant fields of technology. Societally, the advancements in secondary sources will contribute to improved healthcare outcomes. For example, in cancer treatment, more precise and effective therapies such as laser-plasma electron or proton beam therapy could be enabled.
Additionally, the environmental benefits of more efficient and compact secondary sources align with global sustainability goals. In the defence realm, these technologies will enhance capabilities based on advanced semiconductors, for example, in secure communications and real-time AI applications, providing strategic advantages and ensuring European technological sovereignty. Overall, this Grand Challenge will strengthen European technological autonomy and foster economic growth while addressing critical societal and defence needs.

Partners and Stakeholders
The NextGen Photonics Grand Challenge can benefit from Europe's ecosystem in advanced photonics. Potential partners include RTOs like DESY, Fraunhofer, IMEC, or CEA-Leti, which provide vast experience in both the development and application of secondary sources. Likewise, industry stakeholders such as ASML, ZEISS, TRUMPF, Bruker AXS GmbH and others play crucial roles in industrialising, integrating and applying these technologies in various sectors, including semiconductor manufacturing, battery production, health applications and material research. The collaboration of these partners and stakeholders will drive the advancement of secondary source technologies, ensuring their successful development and commercialisation in Europe.

Recommendations for Public Action and Investment
To realise the full potential of the Secondary Sources grand challenge, substantial public investment will be essential to overcome the high-risk, high-capital barriers. The required funding must support the entire innovation value chain, ensure European technological sovereignty, and de-risk private sector engagement at critical stages (**TRL 5 to TRL 9**). The estimated public investment required over a 10-year timeframe is **€300 to 800 million**, allocated across key pillars:

1. **R&D (€150-€300 million)**
   Funding of applied research, photonic systems, targets and metrology, system-level integration, and early demonstrators. Includes academic-industry consortia, technology validation in labs, and industrial demonstrators.

2. **Industrial Pilot Lines and Manufacturing Scale-Up (€100-€400 million)**
   Includes investments in:
   - Dedicated industrial secondary pilot lines
   - application qualification (TRL 6–7)
   - Establishment of the first key applications.

3. **Skills, Training, and Coordination (€50-€100 million)**
   - Training programmes for photonics engineers and system designers.
   - Support for interdisciplinary PhD and postdoc programmes.
   - Coordination actions across the EU27 to harmonise efforts and manage large-scale consortia.

Expected Outcome
This scale of investment reflects the strategic importance of securing leadership in photonic-driven secondary sources. The investments would have a huge impact on the technology path towards industrial applications of secondary sources. They would, as a secondary effect, support the development of laser systems needed for future laser fusion.