MANUFACTURING

➢ **Main socio-economic challenges addressed** (~1 page)

This part should briefly describe the most relevant missions and markets to be addressed by the work group's technical field

Europe must face new challenges in all production-related processes, from materials and logistics to the manufacturing processes themselves. Digitalisation and a sustainable and circular approach to production and materials will continue to be the basis for a competitive, sustainable industry in Europe. However, an essential prerequisite is the sovereignty of production processes and their flexibility. In this context, digitalisation and digitised production processes are indispensable keys to success. But we need both: flexibilization of existing processes, fully digital production and process integration, and at the same time innovative new approaches for future applications. The following photonics-based production topics will provide solutions for a forward-looking European manufacturing and machining industry, addressing three main aspects:

1 Production sovereignty
Photonics is a versatile tool to realise the "first-time right" approach with the highest quality and reproducibility. Near-market production capacities are scalable and process chains can be set up locally, from single products up to mass production, therefore shortening and securing the supply chains and achieving a higher level of production sovereignty in Europe.

2 Energy and material efficiency
Photonics is a clean and sustainable tool in production processes, as the use of the energy provided to a workpiece is specific and selective, i.e. localised and adapted to the process requirements. Application-specific beam shaping and control of the interaction in the workpiece are, along with energy-efficient flexible laser systems, the key to efficient processes.

3 Digital production
Photonics is a flexible and fully digital production tool. Through its adaptability to different operating conditions and the use of AI and simulation, flexible, reconfigurable and transformable production systems and process chains can be realised. Furthermore, interoperability with other tools in the value chains is easily achieved by the fully digital approach.

These approaches will address manufacturing challenges in the automotive, aerospace, shipbuilding, rail, oil and gas, medical instruments, printing, displays and white goods sectors.

Europe is in a strong position to meet these challenges: its strength in industrial photonics is part of its leadership in industrial technology, including machine tools and robotics. The global market for industrial laser systems – the largest manufacturing category for photonics – was worth €17.4 billion ($19.5 billion) in 2019 [Tematys Report 2020] (€11.4 billion in 2016). European photonics companies control roughly one-third of this market.

Our mission is to support industrial manufacturing by implementing photonics-based solutions for a resource efficient and clean way of production. The products addressed cover a wide spectrum, from tiny PICs (Photonic Integrated Circuits) and sensors to core mobility elements such as fuel cells, from sheet metal/steel to complex composites, from functional materials such as silicon and compound semiconductors to brittle sapphire and glass. By extending the photonic production processes towards opto-electrical systems, packaging and integration, the technology field of quantum technology / computing and optical data processing are accessible.

New set-ups for laser sources and systems will lead to greater flexibility towards multi-purpose systems, up to universal machines, where subtractive and additive processes such as cutting, drilling and welding are accessible in one system.

In addition, ultra-fast high-power laser systems will pave the way to “secondary sources” where photons help to generate specific high-energy particles (electrons, protons, neutrons) and x-ray with numerous new application fields in the future, from industrial diagnostics to cancer treatment up to fusion for energy generation at the far end.

The implementation of these approaches will lead to European leadership in competitiveness and energy efficiency in all production processes and process chains in this technology segment.

➢ **Major photonics research & innovation challenges** (~2 pages)

This section should describe the major photonics research & innovation challenges which will contribute to address the adjunct markets.

Based on the past SRIA for Lasers and Systems for Manufacturing and related processes a revised version has been set up and new major photonics research & innovation challenges have been identified. These challenges can be summarized in 5 topics related to photonic systems for manufacturing and photonic processes for manufacturing:

1. Efficient and flexible laser systems and components
2. Beam delivery, shaping and deflection systems
3. Digital photonic production processes
4. Quality control and non-destructive testing
5. New laser-based processes

Laser beam sources: Lasers for Manufacturing in the KW-class have become commodity with high power fiber lasers, high brilliant diode lasers and flexible disc lasers. However, due to the increasing energy costs, the efficiency of this lasers has to be increased and new solutions for low cost of ownership for photons have to be found. One solution can be a highly selective manipulation of single and multiple beam arrangements. Therefor laser beam sources with high efficiency and adaptable beam parameters will be necessary to follow industrial needs. Especially the flexible change of wavelength from UV to IR to be able to adapt the energy deposition to the material or a fast change of pulsing capability from fs to cw in one device will lead to higher precision and high productivity in laser manufacturing. Higher beam intensities and process-adapted beam distributions are vital for challenging applications, for example on high-temperature materials and fibre composites. This improvement will enable fast processing that is not harmful to the material.

With the availability of high-power ultrafast lasers new manufacturing processes have been established. However, for mass production and large-scale processing multi-KW-ultrafast lasers are needed with related fast beam guiding and beam modulation systems. For that, new and stable laser materials and laser component materials are need as well as new design principles with higher power stability. Moreover, highly agile lasers with flexible pulse widths, wavelengths, and pulse energies are needed which will unlock new applications in electronics, lightweight construction, ceramics, glass and metal processing, leading to continuous, and digital, photonic process chains.

As a candidate for wavelength independency, high efficiency and multi-beam approach with the highest potential of improvement, compact and efficient high-performance diode lasers can be used, which are the basis for pumping both solid-state lasers, with a broad spectrum of wavelengths (depending on the active medium), and for direct applications as well.

Beam Guiding and beam manipulation: The improvement of the energy deposition with respect to the material to be processed requires a selective choice of wavelength, which leads to a specific absorption length of the radiation. This can be realized by selecting the right laser wavelength as described above. Secondly, a process dependent energy deposition also requires a specific beam distribution in time and space. For the realization of process specific beam distributions, powerful optical fibres and beam guidance will be required, especially for the extended wavelength and pulse duration ranges that are expected. For this purpose, innovative material systems and system designs have to be developed for the transmission of laser radiation without loss or distortion, even in the mid and far-infrared range. For further integration into machine tool technology, ultra-fast scanning systems will be needed for flexible production systems, enabling process speeds beyond 1.000 m/s, with simultaneous high positioning accuracy and flexibility for manageable processes in production lines.

Moreover for enhanced positional flexibility and the free choice of energy distribution ultrafast scanning devices are required, which should use all-optical scanning principles and switchable multi-beam arrangements. All these new technologies should be available for the use of high-power lasers in the KW-class for cw laser and for ultrafast laser.

With adjustable or programmable beam shaping, optimisation by multi-space algorithms, rapid quantitative feedback and beam distribution systems with (sub) micrometre resolution and high performance smart machining systems will be available, allowing a rapid change in production cycles and batch sizes. Additional flexibility might be gained by combining laser sources with different parameters (wavelength, energy, etc.) to have multiscale functionalisation or multi-function in the same process. Combined with flexible systems for multi-beam handling and fast beam switches, this will result in a new form of machine tool, enabling highly flexible and energy-efficient production and different laser materials processing (for instance, welding, cladding, surface structuring, drilling, surface cleaning and ablation)

Digital photonic production: Laser processes are perfectly suited for fully digital production. With fast beam scanning systems and flexible process parameter changes different applications can be addressed using on single tool. To achieve even high production flexibility and production efficiency new approaches for hybridization of laser processes are necessary, such as the combination of additive technologies and fast texturing and AM with mechanical machining.

With digital addressable beam distributions different components can be processed without changing the manufacturing equipment. Together with self-learning and self-optimizing algorithms for the selection of processing parameters, autonomous production systems also combining different laser-based processes can be realized. Here the use of AI, and collective intelligence as well as technology experience from former manufacturing steps and reverse engineering of beam parameters will be key issues for short setup times and highly reproducible production. This first-time-right-approach will be a key parameter for transferring production capabilities from abroad back to Europe with shortening and securing the supply chain. As a consequence and necessary prerequisite, novel design tools for advanced photonic processes and optical manufacturing components (metasurfaces, freeforms, etc.) are required, which allow reconfigurable manufacturing equipment for high-end products/components. Digital twins of all laser-based production processes and equipment as well as a general framework to manage, extend and use of them will be an ultimate tool for increasing productivity and flexibility.

Quality Control and Non-Destructive-Testing: To realize a fully digital first-time-right- photonic production a powerful in-process metrology is necessary using advanced VIS / IR and multi- and hyperspectral sensing systems. With these systems high product yield while simultaneously maintaining high quality will be ensured. This will apply to all laser manufacturing processes like ablation, welding and additive manufacturing processes, in which both defects and deviations from the target geometry must be detected and compensated for during the manufacturing of the components. High-performance sensor and vision systems such as high-speed cameras, and efficient algorithms for flexible, inline-use are necessary to acquire the relevant data from the process and product. Together with self-learning intelligent process control a highly flexible and adaptive production system can be realized.

Large amounts of potentially useful data can be generated during laser-based production. The future challenge is to maximise the value of this data, which is expected to be achieved by using artificial intelligence processes. Here, reduced metamodels will allow real-time evaluations and early prediction of product quality, going up to lifetime predictions. The information generated will flow into comprehensive databases, potentially reducing process development costs by a significant margin.

New laser applications and processes: Ultra high intensity laser processes allow the generation of secondary radiation from the interaction of the initial laser beam with selected materials. Here EUV, x-ray and other wavelengths can be achieved to realize new micro- and nano-structuring processes or selected material modifications. For this radiation sources highly stable crystals and affordable pumping sources are necessary. Hard- and soft-x-ray sources require new stable laser and radiation source components to set up new manufacturing systems for pushing the technology for the manufacturing of e.g. metamaterials and functional surfaces. Especially materials with nonlinear optical properties or adjustable refractive index for printed optical systems are needed to adapt the radiation source to the needs of the manufacturing process. This will lead to new production capabilities for new types of sensors and components for electronic industry.

By using highly efficient laser systems the energy footprint in production can be reduced with new laser-based processes by replacing traditional high energy consumption systems such as gas furnaces, burners and even traditional stamping machines. Here the combination of different laser wavelengths and parameters with adapted new material formulations will have strong impact on energy efficient manufacturing processes. The combination of laser processes with conventional processes can result in new manufacturing solutions and a higher degree of freedom in the choice of materials and tools.

- **Cooperation needs with Horizon Europe Missions or partnerships**

(~0.5-1 page)

This section should mention any relevant cooperation partners regarding the Horizon Europe Missions or partnerships.

Photonic manufacturing is a key technology for a large number of applications. Therefor cooperation is needed with other disciplines and application-oriented partnerships. Photonics is a cross-sector technology and pan-European cooperation along the entire value chain will be essential for future progress and success. For example, in the production of batteries and fuel cells laser based manufacturing is a key element within the process chain and all relevant players need to be involved in respective collaborative projects, research networks and clusters, providing novel and innovative solutions to manufacturing problems.

To implement laser-based manufacturing solutions in Industry 4.0, close cooperation with the Partnership “Made in Europe” (EFFRA) has already been established and should be continued on many levels. This also applies to the Robotics Partnership and towards data analysis, artificial intelligence and machine learning sectors. Moreover, the Batt4EU Partnership, the Clean Hydrogen Partnership, the 2ZERO Partnership as well as the Water4All Partnership are potential partners to launch cooperative calls.

Close cooperation between corresponding work groups within the photonics sector will also be essential. Given that sensors will play a major role in the digitalisation of manufacturing process information and because components and integrated systems will be used in complex process monitoring systems, cooperation with the Photonics Core Work Group will be vital.

While industrial manufacturing touches the realms of food production and health products (for example, in Process Industries or Additive Manufacturing), the Health Work Group will be a formidable partner. And, given that the Climate, Mobility & Energy Work Group acts as a “customer” of production systems, towards the end of the process chain, cooperation with the automotive and transport sector will be essential.

➢ **Proposed roadmap for 2025 – 2030** (~1-3 pages)

	2025	>>>	2028	2030
Overview technology challenges	**Digital photonic production** **Energy and material efficiency** **Production sovereignty**			
Critical technological milestones	Flexible laser sources and high-speed beam deflection systems	Simulation and digitalisation of processes	Connected, digitalised production	
Research and innovation challenges	**Efficient and flexible laser systems and components** Laser beam sources with high efficiency and adaptable beam and pulse parameters Material, coatings and components for high power/high intensity beams High energy and highly agile ultra-short pulse lasers High performance diode lasers (cw and pulsed) with different wavelengths Multi beam lasers **Beam delivery, shaping and deflection systems** Adjustable beam shaping with controlled energy deposition in space and time Ultra-fast precision scanning systems (>1km/s) Switchable multi-beam arrangements Novel optical fibres for flexible use High-speed monitoring and quantitative feedback systems Multi beam switching and processing Miniaturized interchangeable optical processing systems Multi-use focus head for flexible machines **Digital photonic production processes** AI assisted processes with adapted parameters and fully digital control Automated parameter adaption for autonomous production systems Design tools, simulation and digital twin for advanced, flexible process chains Reconfigurable manufacturing equipment for photonic based production Parallel processing for high throughput **Quality control and NDT** Multi-sensor real time process control for zero-defect production processes On-line non-destructive testing of laser manufactured parts Process optimization based on novel in-line / at-line photonic measurement Data analysis, meta modelling and quality prediction **New laser-based processes** Ultra-high intensity laser for secondary sources (EUV, X-ray, particles) Laser-based processes replacing conventional heating / carbon-based processes			
Joint actions required	Made in Europe (EFFRA); Robotics; SPIRE			

Appendix

Timeline and Document Structure

Photonics21 Strategic Research and Innovation Agenda (SRIA) –

Proposed timeline

Until mid-November 2022:	Follow-up Photonics21 workshops
Until end of November 2022:	First draft of the introduction chapter provided by the Photonics21 Secretariat, circulation for feedback First draft of the Work Group chapters, circulation to Photonics21 Work Groups for feedback
Until 15th January 2023:	Second draft of the Work Group Chapters, circulation to the Board of Stakeholders, two weeks' time for feedback (end of January 2023)
Until December 2022:	Photonics21 secretariat responsible for photo collection
Until mid-February 2023:	Final draft of the Photonics21 SRIA Circulation to the Board of Stakeholders
February/March 2023:	Proof-reading of the photonics roadmap
March/April 2023:	Final editing & layout of the SRIA
End of April 2023:	Publication of the Photonics21 SRIA alongside the Photonics PPP Annual Meeting 2023