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3D printing for the machine tool industry

This report was prepared by Els Van de Velde and Daniela Kretz (Idea Consult).

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European Innovation Council and Small and Medium-sized Enterprises Executive Agency (EISMEA)
Unit I-02.2 — SMP / COSME Pillar
E-mail: EISMEA-SMP-COSME-ENQUIRIES@ec.europa.eu

Directorate General for Internal Market, Industry, Entrepreneurship and SMEs
Unit D.2 — Industrial Forum, Alliances, Clusters
E-mail: GROW-ATI@ec.europa.eu

European Commission
B-1049 Brussels

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Section 1

1. Background and objectives of the report

Background

The Product Watch Reports have been developed in the framework of the 'Advanced Technologies for Industry' project and serve to identify and analyse 15 promising ATI-based products and their value chains, with an assessment of the strengths and weaknesses of the EU positioning.

Promising ATI-based products can be defined as "*enabling products for the development of goods and services enhancing their overall commercial and social value; embedded by constituent parts that are based on AR/VR, Big Data & Analytics, Blockchain, Cloud, Artificial Intelligence, IoT, Mobility, Robotics, Security & Connectivity, Nanotechnology, Micro-nanoelectronics, Industrial Biotechnology, Advanced Materials and/or Photonics; and, but not limited to, produced by Advanced Manufacturing Technologies*".

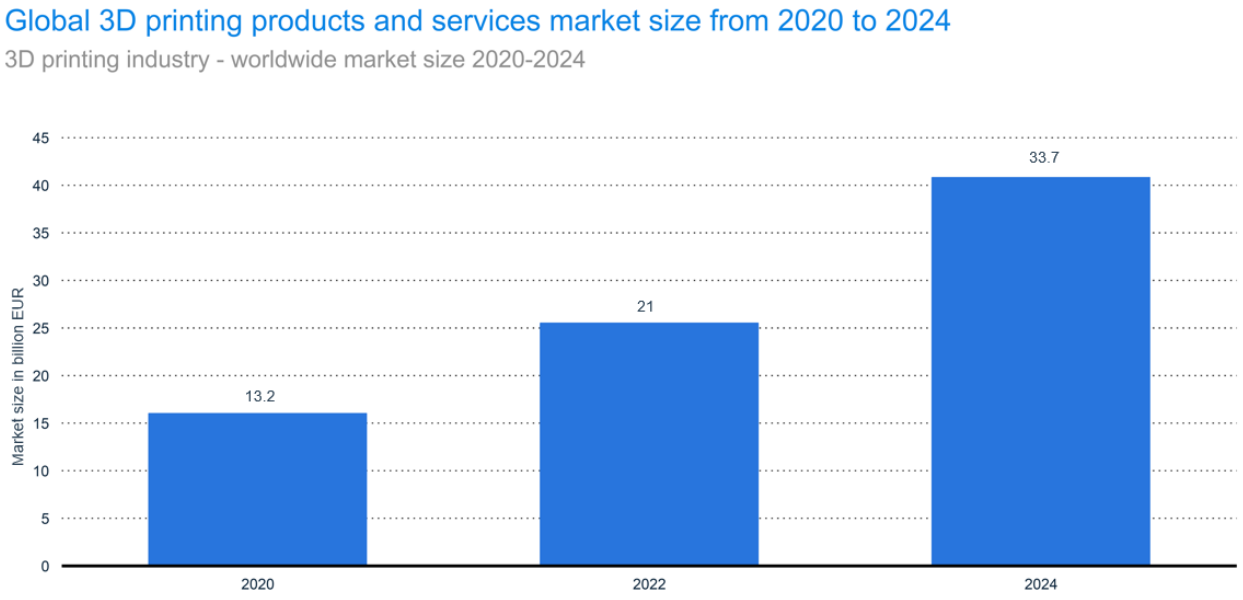
1.1 Background of this report

The twin green and digital transitions highlight the importance of sustainability, while also making use of digital, as well as Advanced Technologies. The push for a sustainable and green economy links with the transition to a low carbon economy, where fewer resources used result in reduced emissions, but moreover includes resource efficiency and the shift towards a circular economy. Advanced technologies such as the Internet of Things, Artificial Intelligence and three-dimensional (3D) printing, to name a few, have the potential to contribute to the transition across a multitude of sectors, ranging from mobility and ICT, to automotive and manufacturing, among others. The importance of drawing upon these advanced technologies in support of the twin transition is building across sectors and value chains.

3DP technologies and market. Three-dimensional printing (3DP) technologies represent innovative manufacturing solutions with a great potential to revolutionise manufacturing and production processes through increased design freedom. 3D printing is highlighted as a technology that is central to digital transformation, and part of the fourth industrial revolution - Industry 4.0.[1] Through a layer-by-layer addition of material, highly customised, complex parts with structural properties not achievable by mass production, can be designed, and present an opportunity to transition to mass customisation in various sectors. In 2019 the global 3D printing market size was valued at €9.55 billion[2] and is expected to grow at a 15% Compound Annual Growth Rate (CAGR) from 2020 to 2027[3] and 26.4% between 2020 and 2024 (see Figure 1).[4] Some of the opportunities for application areas include prototyping and the printing of functional parts. Materials for 3D printing include metals, polymers, as well as biomaterials. Where polymers are considered a low-cost entry point, typically used for prototyping, quick prints and printing of models, metals printing is, due to its higher costs, for parts requiring specific qualities, such as strength and durability, among others. The investment costs for metal 3D printing start at €0.5 million, which can also be attributed to the high costs of post-processing (milling, grinding, etc.). In addition, biomaterials (such as WF, lignin, palm fibres and polylactic acid (PLA)) can also be used possibly as a replacement for petroleum-based polymers and include applications in medical devices.[5]

[1] OECD. (2020). The Digitalisation of Science, Technology and Innovation: Key Developments and Policies, https://www.oecd-ilibrary.org/science-and-technology/the-digitalisation-of-science-technology-and-innovation_b9e4a2c0-en
[2] Exchange rate 1 EUR = 1.21192 USD, 15 February 2021
[3] Grand View Research. (2020a). 3D Printing Market Size, Growth & Trends Report, 2020-2027, https://www.grandviewresearch.com/industry-analysis/3d-printing-industry-analysis
[4] Statista. (2020). Global 3D printing products and services market size from 2020 to 2024, https://www.statista.com/statistics/315386/global-market-for-3d-printers/ Original source Wohlers Associates. (2020). Technical, Market, and Strategic advice on Additive Manufacturing 3D Printing Rapid Product Development, http://wohlersassociates.com/
[5] Wasti, S. and Adhikari, S. (2020). Use of Biomaterials for 3D Printing by Fused Deposition Modeling Technique: A Review, Frontiers in Chemistry, https://www.frontiersin.org/articles/10.3389/fchem.2020.00315/full

Figure 1: Global 3D printing products and services market size from 2020 to 2024 in billion EUR[6]



Source: adapted from Statista, 2020 original source Wohlers Associates, 2020

Machine tool industry. The global machine tool industry has an estimated market size of roughly €63.7 billion in 2019 and is expected to grow with a CAGR of 4% from 2020 to 2027.[7] The industry growth is driven by the use of digital technologies, such as computer-aided manufacturing as well as the demand for mass production across several industries, such as automotive and defence, creating demand for more machine tools. Traditional market segments include lathe machines, milling machines, laser machines, grinding machines, welding machines and winding machines, among others. Industry 4.0 represents an important transition for the machine tool industry to increase efficiency, maximise speed and increase precision.

Zooming in on 3D printing for the machine tool industry. While the application of 3D printing in the machine tool industry are underexplored, this report zooms in on the application of this technology in this industry to be able to highlight some of the potential opportunities, as well as several challenges that are present. At present only a few industry players are producing and testing (inhouse) the use of 3D printing in machine tool production, typically for prototyping, or small series production.[8] Due to the high costs of equipment, this is often subcontracted or carried out together with service providers. Many industries, such as automotive, aerospace and defence, embrace the use of 3D printing for tooling due to advantages such as lead time reduction, cost reduction, improved functionality and increased ability to customise parts.[9] There are concrete market opportunities in the combination of both technologies for serial production and it is essential to support the interest of machine tool manufacturers further in exploring these opportunities by creating training, field lab visits and funding opportunities to support the development of business cases. A key area of interest is also exploring the use for critical parts, as well as electronic parts of machinery.

[6] Exchange rate 1 EUR = 1.21192 USD, 15 February 2021

[7] Grand View Research. (2020b). Global Machine Tools Market Size, Share Report, 2020-2027, https://www.grandviewresearch.com/industry-analysis/machine-tools-market

[8] VDW. (2016). Additive Manufacturing: Potentiale und Risiken aus dem Blickwinkel der deutschenWerkzeugmaschinenindustrie, Verein Deutscher Werkzeugmaschinenfabriken e.V. (VDW), Frankfurt am Main

[9] Cotteleer, M., Neier, M., and Crane, J. (2014). 3D opportunity in tooling: Additive manufacturing shapes the future http://www.advice-manufacturing.com/support-files/3d-system-3dp-tooling.pdf

Figure 2: Examples of application of 3D printing for machine tool parts

Source: VDW, 2016, obtained from Renishaw/LBC GmbH

Linkages with other Advanced Technologies. 3D printing in its application can be connected with several other advanced technologies, notably, Artificial Intelligence (AI), sensors and robotics in the machine tool industry. AI is particularly interesting in relation to inline inspection, to support quality control and defect detection. Machine learning combined with AI are key in supporting the notion of zero-defect manufacturing approaches for the machine tool industry.[10] Sensors are important for monitoring and detection of early disturbances in the wearing down of machine tool components. Sensor solutions can be used to improve production efficiency, e.g. SICK provides intelligent sensor solutions to make machines and systems safer, faster and more flexible, while also offering quality control and track-and-trace options.[11] Robotics provide an opportunity for automation, and increased productivity. The most common machine tool robots include handling workpieces, palletising workpieces, linking machines, machining workpieces and handling tools.[12] Robotics can draw upon 3D printing for the integration of electronics into the surface, resulting in products such as sensitive grippers able to adjust to products of different sizes. Industrial interest for 3D printing electronics comes from Heidelberger, Airbus and Stäubli, among others.

Future trajectories for 3D printing. Several trajectories for the application of 3D printing can be identified for the years to come, including:

- Multi-materials: the use of multi-materials refers to the printing of two or more materials at the same time. This is particularly interesting for its applications in printing complex parts with filament structures integrated, as well as multi-coloured objects, while at the same time offering time savings.[13] Simulation tools to support multi-material printing are still in development and can greatly support the uptake.
- Onshoring: Referring to the increasing importance of local production with reductions in transport times, as well as offering opportunity to quick response manufacturing, especially of rare and obsolete but also spare parts. Local production is expected to be more important in the years to come than weight reduction, which is not a key priority in the machine tool industry.
- Sustainability: increasingly important is also the overall sustainability that 3D printing can offer, not only through reduced transport times, but also the potential for lower energy consumption, material savings and waste considerations.[14]
- 4D printing, which entails the opportunity to add another functionality to a part via the addition of certain materials and their associated properties, which enable new functionality (e.g. shape

[10] CECIMO. (2020c). CECIMO Position Paper on Artificial Intelligence, https://www.cecimo.eu/publications/cecimo-white-paper-on-artificial-intelligence/
[11] SICK. (2014). Efficient Solutions for the Machine Tool Industry: Achieving more with intelligent sensors, https://cdn.sick.com/media/docs/3/43/543/industry_guide_sensor_technology_solutions_for_the_machine_tool_industry_en_im0018543.pdf
[12] KUKA. (2021). Optimizing machine tools through automation, https://www.kuka.com/en-be/industries/metal-industry/machine-tooling
[13] BCN3D. (2020). Multi-Material 3D Printing: Benefits and How It's Done, https://www.bcn3d.com/multi-material-3d-printing-benefits-and-how-its-done
[14] AMFG. (2020). How Sustainable is Industrial 3D Printing? https://amfg.ai/2020/03/10/how-sustainable-is-industrial-3d-printing/

change) to be achieved. The technology is still in a R&D phase, including examples where boxes could, with a certain stimulus, unfold themselves[15] or a gripper that grabs objects when the temperature is optimal, or objects that will change or retain shape with certain stimuli.[16] See Figure 3 for an example of nitinol alloy for the satellite panel opening system.[17]

Figure 3: Example of nitinol alloy for the satellite panel opening system using 4D printed hinges

Source: NASA, n.d.

1.2 Objectives of this report

Advanced technologies are rapidly changing machine tool production today. Machine tool manufacturers still struggle to adopt the technologies that are suitable for their specific practices, often due to high investment cost, both in equipment and in terms of skills. Specific evidence for all types of 3D printing uptake in machine tool production is needed to foster the uptake beyond its use in prototyping and towards serial production.

The report specifically zooms in on the use of 3D printing in the machine tool industry, providing an overview of the value chain and relevant stakeholders. The objective is to map the key players in the 3D printing technology for machine tool value chain, as well as to identify their strengths and weaknesses, also in comparison with international players. Analyses are based on desk-research, interviews as well as on the internal expertise of IDEA Consult on the subject.

[15] Young, M. (2019). What is 4D Printing? – All You Need to Know, https://all3dp.com/1/4d-printing

[16] Sculpteo. (n.d.). 4D Printing: A technology coming from the future, https://www.sculpteo.com/en/3d-learning-hub/best-articles-about-3d-printing/4d-printing-technology/

[17] NASA. (n.d.). Shape Memory Alloy Mechanisms for CubeSats, https://ntts-prod.s3.amazonaws.com/t2p/prod/t2media/tops/pdf/LEW-TOPS-135.pdf

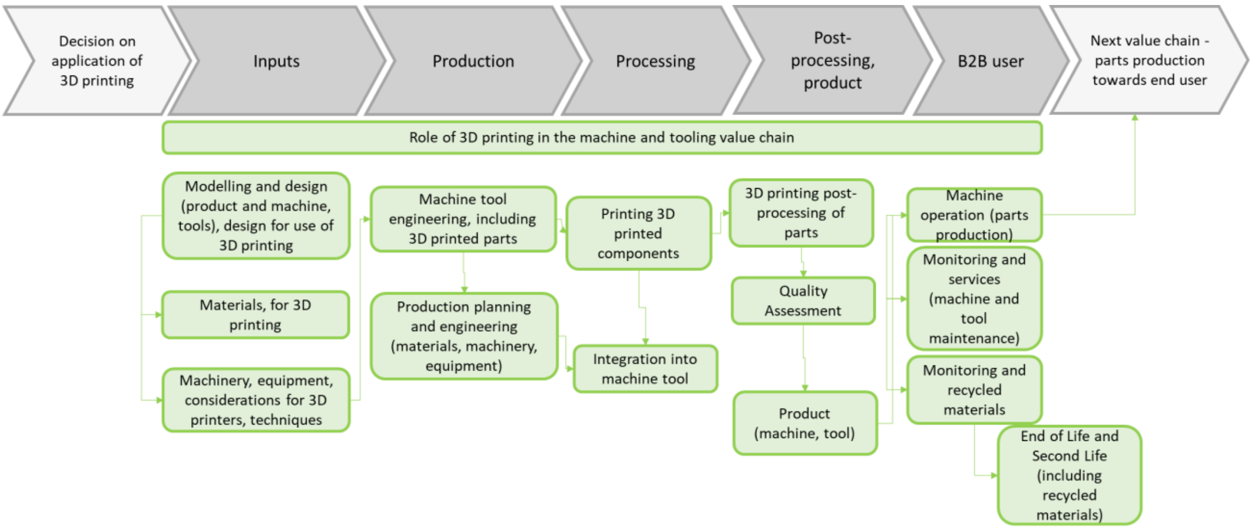
Section 2

2. Value chain analysis

2.1 Value chain structure

3D printing represents a dynamic and disruptive technology that plays a key role in the future of the machine tooling industry. The value chain structure can be outlined into key segments, as highlighted in Figure 4 below. The segments in grey depict the main elements of the machine tool value chain for the production of parts in a B2B setting, with a separate value chain towards the end use indicated by the exiting arrow in light grey. This represents the 'next value chain' for which the machine or tool part is being produced and goes towards the end user. The part of the figure in green refers to the specific use and role of 3D printing in the machine tool industry value chain, as related to these key segments.

Figure 4: The machine tool value chain (grey boxes) with the role of 3D printing (green boxes)



Source: IDEA Consult, based on TWI et al., 2017, Siemens, 2021, European Commission, 2017 and interviews

Prior to the value chain: Decision making on the use of 3D printing technology. 3D printing and traditional production techniques are considered complementary technologies, rather than technologies that are interchangeable. The means of integrating 3D printing into the machine tool value chain can include the use of 3D printing following the use of traditional techniques, e.g. to add features or bring together individual parts additively, or by using 3D printing together with subtractive techniques, departing from a 3D printed design. Both cases present an opportunity for the machine tool industry that is still under development. Prior to integrating the technology into the value chain, it is important to address the following criteria: time, cost, volume and functionality. When producing the part, one needs to take into consideration what it will be used for, e.g. spare part, specific functionality sought, etc. Examples of the criteria to consider include:

1. Time: e.g. the urgent need for a spare part, such as in ship building and maintenance where there are high standstill costs, then 3D printing may offer a solution. Likewise, moulds for testing and customer engagement with the proposed part represent an opportunity for 3D printing as it shortens (or removes) delivery times (upwards of 6 weeks when coming from China).
2. Cost: costs for 3D printing, especially with metals, remain high. It is important to consider whether there is a sufficient business case for applying 3D printed techniques. Integrated service providers can be helpful in supporting production of parts (e.g. by supporting design and printing of parts). Moulds made using high quality materials can also enable more production using the same mould, and thus enabling the business case for a high-quality 3D printed mould.

3. Volume: Generally, 3D printing is still applied for small numbers, including for prototyping and small series production. If only a small series are needed, e.g. less than 100, 3D printing can also offer an optimal solution.
4. Functionality: 3D printing offers design freedom, and when combined with a digital twin and simulation, offers new possibilities such as the use of complex internal structures, e.g. designing mould inserts to have conformal cooling. Further opportunities include materials savings, structural integrity, etc.

Inputs. Looking at the value chain itself, inputs in the context of the use of 3D printing include modelling and design, which are reflected upon once the decision to use 3D printing has been clarified. Based on the decision, also the materials and the associated machinery, further equipment and techniques will be reflected upon. Materials in the machine tool value chain will either predominantly be metals or polymers, however multi-materials (e.g. mixing biodegradable and engineering grade polymers prior to printing (single nozzle design fused filament fabrication) or printing both polymers with separate nozzles to make one object (multi-nozzle design fused filament fabrication)) represent a future oriented opportunity.

Production and processing. The production itself refers to the linkage between the machine tool production and the use of 3D printing. Will first the machine tool be produced, perhaps in several parts, and then 3D printing will be applied to connect, or add properties to the part? Or will 3D printing techniques be applied in a first instance, and then treated? Depending on this decision, the production and processing steps are organised accordingly. This decision is reflected in the engineering of the machine tool, including the 3D printed parts and how the part fits with the overall production planning and engineering (e.g. non-3D printed components and wider parts of the machine tool). Where deemed appropriate to apply, 3D printing of the relevant parts will be carried out and integrated into the machine tool.

Post-processing, product. 3D printed parts require a certain degree of post-processing, to remove support structures and carry out surface treatment. In the area of metals, solution providers for this specific value chain segment include RENA (formerly Hirtenberger)[18], who have designed a post-processing technique to remove supporting structures, and clean, treat and protect surfaces of metal parts in an integrated solution. Quality assessment remains an important part of 3D printing, due to the degree of variation between printed parts. Once a quality assessment is complete, the product is ready for integration into the machine tool part.

B2B versus B2C as a niche market. The value chain focuses on the B2B setting, where the machine tool value chain segments leading up to the production of parts, point towards a separate value chain for the end use of the part. In a B2B setting, the machine tool produced will enter into operation for the production of the product of the end user. Nevertheless, it remains important to monitor and maintain the machine tool product delivered by this intermediate value chain. This includes also considerations of materials, and the possibilities for end of life and second life of the parts. This value chain thus represents the machine tool segment, in the production of an end product in a sector such as automotive, aerospace, among others. By comparison, some 3D printing solutions offer a direct B2C relationship, however this remains a niche market for e.g. custom running shoes, glasses.

2.2 Key actors in the value chain

Along the value chain, a series of key actors can be identified that are vital to the realisation of the proposed value chain above. A non-exhaustive list of key actors includes:

- 3D printer manufacturers
- Material suppliers
- Service providers
- Machine tool manufacturers applying 3D printing
- Skills and training institutes
- Legislators, regulators and certification bodies

3D printer manufacturers. 3D printer manufacturers can be grouped based on the materials printed, e.g. metals, polymers, biomaterials. For a list of companies developing 3D printers using metals, please see the Product Watch Report '3D printing of hybrid components'.[19] In addition to metals, also inkjet-based printing represents an important technology for the machine tool industry. Inkjet can be used for

[18] RENA. (2021). RENA Austria, https://www.rena.com/en/company/rena-austria/
[19] Van de Velde, E. and Kretz, D. (2020). Advanced Technologies for Industry – Product Watch: 3D printing of hybrid components, https://ati.ec.europa.eu/reports/product-watch/3d-printing-hybrid-components

the printing of electroconductive nano particle-based materials. A list of some relevant manufacturers is included in Table 1 .

Table 1: Non-exhaustive list of 3D printing inkjet printer manufacturers

Company	Country	Website
3D systems	United States	https://www.3dsystems.com
Ceradrop	France	http://www.ceradrop.com/en/
ChemCubed	United States	https://www.chemcubed.com
Inkbit	United States	https://inkbit3d.com/hardware
NanoDimension	Israel	https://www.nano-di.com
Notion Systems	Germany	https://www.notion-systems.com/home.html
Stratasys	United States	https://www.stratasys.com

Source: Compiled by IDEA Consult based on Molitch-Hou, M., 2020 and interviews

Material suppliers. Different materials are required for 3D printing, depending on the type, including powders for metal printing, and filaments and liquids for printing of composites and polymers, among others. Metal materials include steels, alloys, titanium and aluminium, among others. Polymer materials include acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), acrylonitrile styrene acrylate (ASA), polyethylene terephthalate (PET), polyethylene terephthalate glycol (PETG), Polycarbonate (PC), Polypropylene (PP) and High-Performance Polymers (polyether ether ketone (PEEK), polyetherketoneketone (PEKK) and polyetherimide (ULTEM)), among others. Hybrid and composite materials represent a mixture of materials to achieve different performance and attributes of the printed product.[20] It is important that materials suppliers are able to provide a certain degree of quality assurance, as the materials, together with the 3D printing machines are key for the cohesion and strength of the final product. Reliable production is needed that can guarantee good results.

Service providers. Integrated service providers, also referred to as service bureaus in some contexts, represent a key group of companies that support sector specific companies in exploring and implementing 3D printing in their business model, production and product. Services can include software development, design, as well as engineering companies providing services to specific sectors, such as automotive, ship building, maintenance. Specifically in the machine tool industry, design and engineering companies are identified as service companies that still need to work further to implement and include 3D printing as a technique in parts production and design. On the long term, service providers support the uptake and contribute to the acceptance of this technology.

Table 2: Non-exhaustive list of 3D printing service providers active in the machine tool industry

Company	Area of activity	Country	Website
AM-Flow	Creating end-to-end production processes based on 3D printing, with an emphasis on sustainable manufacturing	The Netherlands	https://am-flow.com
Ecoparts	Additive metal solutions	Switzerland	https://ecoparts.ch/
Festo Group	Providing integrated solutions for the automation and digitalisation of machine tool producers	Sweden	https://www.festo.com/cms/sv_se/140.htm
Funk MASCHINENBAU GmbH	Your expert for high-tech components, mechanical engineering components, 3D printing and prototypes in metal, plastic and fibre composites	Germany	https://www.funk-maschinenbau.de/
Hofmann tooling	Providing services (prototyping) for automotive industry	Germany	https://www.hoffmann-group.com/GB/en/houk/consulting-and-support/consulting/3d-printing/e/64146/
K3D	Support services for metals 3D printing	The Netherlands	https://k3d.nl

[20] Alexandrea, P. (2020). 3D Printing Materials Guide: Plastics, https://www.3dnatives.com/en/plastics-used-3d-printing110420174/#!

Company	Area of activity	Country	Website
KMWE	Designs, engineers high tech components based on machining, prototyping 3D printing and machining, business case validation	The Netherlands	https://www.kmwe.com/what-we-do/competences/additive-manufacturing/
Materialise	Solutions and services for 3D printing of tools	Belgium	https://www.materialise.com/en/manufacturing/3d-printed-production-tools
Prima Additive	Developing, manufacturing, selling and distributing industrial metal Additive Manufacturing systems worldwide, specialised in lase machinery and services	Italy	https://www.primaadditive.com/
Rapidobject	3D printing services for prototypes and series	Germany	https://www.rapidobject.com/de/Startseite_10.html
RCIT - Radom Center of Innovation and Technology	Helping enterprises develop and implement modern design and manufacturing technologies with emphasis on 3D printing	Poland	https://en.rcit.pl/
RENA[21]	Surface treatment of 3D printed metal parts	Austria	https://www.rena.com/en/innovation/hirtisation/
RICOH	Support automotive, medical and industrial 3D printing	Japan	https://rapidfab.ricoh-europe.com/
SIEVA	Providing services for automotive and other industries	Slovenia	http://www.sieva.si/en/
Spartacus 3D[22]	Industrial expert in additive manufacturing	France	https://www.farinia.com/spartacus3d
TOPOMATIKA	Providing services in 3D printing and 3D measurement	Croatia	https://topomatika.com/

Source: Compiled by IDEA Consult based on VDW, 2016 and interviews

Machine tool manufacturers applying 3D printing. As indicated, machine tool manufacturers are in the stage of exploring the possibilities for 3D printing in their industrial applications. Several companies that produce machinery and tools have in-house expertise rather than relying on integrated service providers. This includes both research and development (R&D) activities as well as applications for prototyping and the production of small series. A non-exhaustive list of companies that are exploring or offering 3D printing as a part of their machine tool production are included in Table 3 below.

Table 3: Non-exhaustive list of machine tool manufacturing companies exploring 3D printing

Company	Application	Country	Website
DMG MORI AG	Global top company in the machine tool industry with over 20 years of experience in 3D printing	Germany	https://be.dmgmori.com/products/machines/additive-manufacturing
Sandvik	Global engineering group with an additive manufacturing programme	Sweden	https://www.additive.sandvik/en/
Atlas Copco	European leading company in the machine tool industry with an additive manufacturing team	Sweden	https://www.atlascopcogroup.com/en
Trumpf	World leader in provision of machine tools	Germany	https://www.trumpf.com/
ISCAR	World leading producer of cutting tools, exploring 3D printing in	Israel	https://www.iscar.com

[21] Formerly Hirtenberger
[22] Part of Farinia Group

Company	Application	Country	Website
	R&D, prototyping and serial production		
Flex Machine Tools	Using 3D printing to produce custom end effectors, spare parts to save costs, relieve machinist involvement in entire production phase, use CNC machines where material properties are essential	United States	https://flexmachinetools.com/
Hofmann tooling	Tooling industry company with a 3D printing competence centre	Germany	https://www.hoffmann-group.com/SG/en/hsg/consulting-and-support/consulting/3d-printing/e/64146/
TE-Connectivity	Integrating machine-to-machine communications, applying integrated electronics and 3D printing	Switzerland	https://www.te.com/global-en/about-te/capabilities.html
LTH Castings	Producing parts of moulds for aluminium high-pressure die castings	Slovenia	https://www.lthcastings.com/
MARSI Group	Producing parts of moulds for polymer injection moulding and providing services for customers	Slovenia	https://marsi.at

Source: Compiled by IDEA Consult based on Statista, 2021 and interviews

Skills and training institutes. Skills and training are a key part of the future of the uptake of 3D printing in the machine tool industry. Design and engineering of the machine and tools are key steps where the conceptual ideas and freedom that 3D printing allow for can be integrated into the entire production. However, with the limited offering of sufficient training and education, at the moment dependent on the programmes available at universities and universities of applied sciences, the uptake will take longer. Some companies, such as FESTO include a programme in their activities to support exactly this type of training. The FESTO Didactic (Skills)[23] is an industrial training and education programme across 176 countries that, among others, aims to foster the development of relevant skills needed for the application of 3D printing.

Legislators, regulators, standards and certification bodies. Without appropriate legislation and standards in place, the potential of 3D printing will not be felt to its fullest, as concerns about the safety of parts will prevent their uptake. The role of legislators, regulators and certification bodies is key in enabling the end user perception towards 3D printed parts. The role is particularly important for risk environment sectors, such as aviation, automotive, aerospace as well as critical infrastructure, especially when it comes to the use of spare parts. Organisations that have a key role to play in the development of standards include the International Standardisation Organisations (for example ISO, IEC, ASTM), European Standardisation Organisations (CEN, CENELEC, ETSI), as well as National Standardisation Bodies.

2.3 Linkages along the value chain

Overall, the machine tool industry value chain is well established with clear linkages along the value chain and amongst the key stakeholders. The same cannot be said for the 3D printing value chain, which is still fragmented and bears the characteristics of a 'technology push'. In order to overcome this misalignment, it is important to bring together technology and integrated solutions providers with the end user, to tackle the sector and value chain specific issues at hand.

Subsequently companies wanting to implement 3D printing into their product or processes can either (i) directly approach a service provider, obtaining final printed parts as a result, (ii) purchase existing systems and use them to produce 3D printed parts, or (iii) internalise several value chain segments.

In addition, so-called Facility Centres can support a supplier in the development and integration of entire value chain segments. Facility Centres are typically R&D&I stakeholders that can help to demonstrate the technology for the specific use and support the supplier in integrating the solution in the value chain

[23] Festo. (2021). Festo Didactic, https://www.festo-didactic.com/int-en/highlights/?fbid=aW50LmVuLjU1Ny4xNy4xMC43NTM4LjQzMTk

for an end user. Several types of collaboration between stakeholders along the 3D printing value chain can be identified:

- To shorten time to market,
- For R&D purposes, related to materials, products, processes, etc.
- To increase market access, with synergies between stakeholders along different value chain segments.[24]

Missing links along the value chain include those at the beginning and end of the value chain, notably between the software developers, as well as the recyclers and the remainder of the value chain. There is a need to bring together value chain stakeholders specifically at the interface between the machine tool industry and 3D printing, in order to support the shortening of the value chain as well as improve the overall interoperability, including ensuring a more fluid transition towards the next value chain and end user.

[24] TWI et al. (2018). AM-motion A STRATEGIC APPROACH TO INCREASING EUROPE'S VALUE PROPOSITION FOR ADDITIVE MANUFACTURING TECHNOLOGIES AND CAPABILITIES: D4.3 Models of business collaboration.

Section 3

3. Analysis of EU competitive positioning

An indication of the EU competitive positioning can be outlined according to the strengths and opportunities as well as the risks and challenges faced. The chapter below presents an overview of these key strengths, opportunities, challenges and risks for 3D printing in of the machine tool value chain.

Figure 5: Overview of strengths, opportunities, risks and challenges identified

• European coverage and supply networks • Technological knowledge in Europe • Technological advantages through the application of 3D printing in the machine tool value chain	**Strengths**	**Challenges**	• Standards • High investment costs • Available skills and know-how • Technological challenges
• Localisation of spare parts' production and maintenance • Increasing need for customisation and complex parts • Transition to mass production • Technological opportunities	**Opportunities**	**Risks**	• Competitive position of the United States and China • Insufficient investment • Technological risks: cybersecurity to recyclability

Source: IDEA Consult

3.1 Strengths

European coverage and supply networks. Compared to the United States and China, the EU is stronger in connecting supply networks, looking at value chains, their optimisation and bringing together stakeholders across regions. For example, the company ASML in the Netherlands works closely with relevant stakeholders throughout Europe, to produce models and assemble completed machines for the semiconductor industry. In addition, there is a good coverage of demonstration platforms and field labs applying 3D printing across Europe. While the technology is still under development, the networks and collaboration are already a considerable European strength. This is further reinforced by the fact that complex producers and buyers of parts are also located in Europe, so there is not only the production, but also the need for such parts within the same market and ecosystem.

Technological knowledge in Europe. A lot of know-how is available in Europe, as the technology and innovation culture in Europe is very high. There is also a degree of openness to new technologies that is judged to be very high compared to the United States, especially when it comes to the adoption of 3D printing techniques. Specifically looking at technologies, Europe is strong in metals printing, as well as inkjet, though there is also a considerable stronghold in inkjet printing head production coming from Japan.

Technological advantages through the application of 3D printing in the machine tool value chain. Technological strengths of the application of the technology in its current form for prototyping, small series and mould production can be identified. These include reduced delivery times, especially useful for spare parts, but also for products where delivery times are long. In addition, 3D printing is particularly strong in the development of highly complex parts, with internal structures, or cooling chambers. Where needed, internal cooling structures can be of a very high added value for the machine tool industry. Other strengths include material efficiency, compared to subtractive techniques as well as increased performance of parts with optimised material distribution.

3.2 Opportunities

Localisation of spare parts' production and maintenance. With the availability of 3D printing come opportunities such as local production, enabled by digital design files that allow for production to take place within Europe and on demand. This can be particularly beneficial to produce spare parts, no longer needing long shipping times (e.g. from Asia) and available on an as needed basis, while also reducing the need for warehouses to house spare parts. In addition, also tools for maintenance and operation can be envisaged to be manufactured on site on an as needed basis, eliminating the time needed to send the machine to the maintenance team. This can result in the improvement of the production time as well.

Increasing need for customisation and complex parts. There is a rising need for 3D printed parts, that goes hand in hand with increasing complexity in moulds, but also any kind of machinery for broader consumption (such as white goods). In addition, customisation requirements in for example the medical industry (e.g. hips, teeth) are also on the rise. 3D printing offers the possibility to eliminate complex equipment (e.g. moulds, drilling jigs) to manufacture spare parts, as well as structural optimisation of parts to reduce stress and mechanical wear. The ability to print increasing complex parts also comes with cost and weight reductions of the individual components and reduces malfunctioning, such as in parts that contain threaded connections, which are subject to loosening.

Transition to mass production. In the long run, the transition to mass production using 3D printing techniques represents a major opportunity to develop from a niche technology to a mass production player. The caveat is the need for the reinvention of mass production to a 'new normal' involving 3D printing, not only for prototyping and spare parts. This is an opportunity that is particularly felt in Europe, and it is not happening elsewhere (e.g. China).[25] Also, inkjet technology has its place here, with machine and tooling looking to design electronics and 3D print them in the machine building process. While this would not necessarily constitute mass production of say 100 machines, the trend towards larger lot sizes could contribute to reshoring the production of electronics back to Europe.

Technological opportunities. In addition to those points touched upon in the above, 3D printing brings with it a series of technological advantages including optimal structural design, as well as adaptable production design, where, for example, grippers for robots as well as orientation and conveyor systems can adjust to new productions and result in costs and time reduction compared to conventional manufacturing. Another technological opportunity is related to materials, where the optimal materials for each part and even hybrid materials are an option to achieve the desired result, but also to be as resource efficient as possible, avoiding foundry scraps (sprues) generated in subtractive methods. Further technological opportunities include those related to other advanced technologies, such as AI, sensors, robotics, and in addition 4D printing, which represents products that change in shape over time. For examples see 'Nitinol alloy for the satellite panel opening system'[26] and 'Structural integrated electronics in 3D printed parts'[27].

3.3 Risks

Competitive positioning towards the United States and China. Europe is strong in the R&D phase of the technology, however with initiatives such as the 'Action Plan for the rapid, healthy and sustainable development of 3D printing industry (2017-2020) in China'[28], China is exemplary in the ability to support selling technologies to companies by offering support for hardware and software for Chinese companies and those from abroad in order to consolidate expertise. The United States have a different approach to 3D printing, preferring a trial-and-error approach that is less heavily reliant on the need for regulation than in Europe. This allows for a certain regulatory freedom for the exploration of the technology to foster the innovative nature. The US-EU trade deal, which was announced in 2019 to cover also 3D printing, would cover also the advancement of regulatory cooperation in the field of common standards' development. The reference to 3D printing is currently missing in the initial phase of the discussions with the Biden administration.

Insufficient investment. In the case that insufficient investment would occur, specifically into the knowledge and technology, as well as the material, there is a risk of a loss of public interest in 3D printing as a technology. In this case, the result would be that other nations will surpass the technological capabilities in the EU, which is currently a stronghold. The EU is a notorious technology leader on production and has strong capacities in 3D printing, and the highest knowledge level on the technology globally lies in Europe. If another country or region would decide to invest more, or apply

[25] Source: interview
[26] NASA. (n.d.). Shape Memory Alloy Mechanisms for CubeSats, https://ntts-prod.s3.amazonaws.com/t2p/prod/t2media/tops/pdf/LEW-TOPS-135.pdf
[27] Mandamparambil, R. (2016). 3D printed structural electronics – the new manufacturing paradigm, http://www.3dprintingelectronicsconference.com/wp-content/uploads/2016/01/Rajesh-Mandamparambil.pdf
[28] Bhunia, P. (2017). China formulates Action Plan for the development of 3D printing industry, https://opengovasia.com/china-formulates-action-plan-for-the-development-of-3d-printing-industry/

the technology in a wider scope, Europe risks to lose its strong position. Sufficient investment in the technology is needed to ensure that the strength remains in Europe.

Technological risks: cybersecurity to recyclability. Select technologically related risks persist, due to the digital nature of the design files, as well as the materials. Specifically, cybersecurity concerns and the ability to protect and track files remains a technological concern. Solutions exist to tackle this; however cyber threats remain omnipresent. This relates also to the issue of Intellectual Property Rights (IPR) and protecting the rights of original part manufacturers, while at the same time enabling, e.g. the right to repair and the creation of spare parts. Legislative and regulatory considerations are important in ensuring that this is adequately considered. Further technological risks lie in the availability of raw materials as well as the recyclability, especially of multi-materials. The highest risk for 3D printing, as well as the sector of advanced manufacturing is the raw material supply chain.[29] (See also the Product Watch Report '3D printing of hybrid components'[30]). Although the use of multi-materials in 3D printing shows clear structural and design advantages, the end-of-life also needs to be adequately considered, in order to ensure that recycling is still possible.

3.4 Challenges

Standards. Standards are an important means by which to ensure that parts and processes follow the necessary procedures to ensure safety and reliability towards end users. It is needed to have a system where a 3D printed tool or part can refer to a specific standard, but currently, there is a lack of harmonised standards for 3D printers and 3D printed products. Standards are important in raising the willingness to accept the technology and its products. The same holds true for machine procedures, qualifications and certifications on stress and fatigue tests, among others. At present, ISO/TC 261/JG 78 (Joint ISO/TC 261-ASTM F 42 Group): Safety regarding AM-machines (relating to harmonised European Standards, Type C-Standard) is working to develop a standard, which will then be taken over by CEN TC 438 (thus an ISO will subsequently become an EN ISO with a specific number). To become a harmonised standard, it will need to be cited in the Official Journal of the European Union.

High investment costs. The high costs of 3D printing, especially inhouse production through the acquisition of machines, materials and expertise remain a barrier for companies to explore further the potential and uses for this technology. Especially metal printing investment costs start around €0.5 million and up. Polymer printing can serve as a lower cost entry point, however functionality is limited to printing polymers, which can be used as samples or prototypes. The 3DP Pan EU platform enables interested organisations to contact suppliers of 3D printing related services[31].

Available skills and know-how. It is important to change the mindset of designers and engineers to be able to allow the further uptake of 3D printing in the machine tool industry. Design approaches differ for 3D printing to conventional subtractive techniques. Most designs in the machine tool industry today are still carried out with mass production in mind. The potential for 3D printing to address challenges, such as part complexity, but also to offer integrated cooling channels is considerable. It is important to reflect on the use of 3D printing in the design phase, as 3D printing is not an interchangeable but rather complementary technology to traditional techniques, and unique approaches are required to reap the full potential that the technology can offer. Skills and training programmes are needed at a greater scale to be able to address this gap, not only through universities and universities of applied science, but also skilling and reskilling programmes for the existing workforce are needed at a more wide-spread scale to tackle this challenge.

Technological challenges. To a large extent, there is not a lot of uptake of 3D printing in the B2B machine tool industry today. This is due to both the general and technological challenges they face. Several technological challenges related specifically to the technology itself can be identified. These include:

- Recyclability and end-of-life specifically for multi-materials and hybrid materials, where recycling is not as straightforward as with mono-material parts.
- Mass production / high volume production are still not within the current grasp of the technology, rather targeting prototyping and small series production.

[29] European Commission. (2020). Critical materials for strategic technologies and sectors in the EU - a foresight study, obtained via: https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

[30] Van de Velde, E. and Kretz, D. (2020). Advanced Technologies for Industry – Product Watch: 3D printing of hybrid components, https://ati.ec.europa.eu/reports/product-watch/3d-printing-hybrid-components

[31] https://3dppan.eu

- The need for heat treatments and finishes on the metal parts made with 3D printing remains a requirement. Post-processing techniques for metals such as those provided by RENA exist.
- Quality control remains a technological challenge, where a drawback remains that parts can differ from one to another, and hence compared to traditional manufacturing techniques, a certain degree of acceptance of the uniqueness of parts is still needed. The characteristics of the pieces obtained with 3D printing may differ from those (with the same chemical characteristics) obtained with conventional manufacturing. Using 3D printing has an impact on mechanical performance and, above all, on fatigue behaviour. Furthermore, the surface roughness of a metal piece obtained is comparable to that of an object obtained with foundry techniques (e.g. investment casting), with the addition of needing to rework the functional surfaces and/or to drill small diameter holes (typically below 4-5 mm). That being said, it is important that, despite differences, each part ensures the same quality. Zero defect manufacturing techniques and inline quality control are needed, which can draw upon machine learning and AI to solve this issue.
- There are currently dimensional limitations of the parts that can be manufactured using 3D printing. However, this limitation will be overcome by the development of gantry machines or machines based on anthropomorphic robots and the use of 'direct energy deposition' process.
- Limitation in the range of materials (metal, polymeric or other) that can be processed using 3D printing.

Section 4

4. Conclusions & outlook

4.1 Conclusions

The importance of strong supporting legislation. Legislation has the potential to further support the uptake of innovative solutions such as 3D printing in the machine and tool industry. Opportunities include the much anticipated Machinery Directive, published on 21 April 2021.[32] The development of harmonised standards to fulfil the essential health and safety requirements of the Machinery Directive is supported, to foster the sustainable uptake of 3D printing, as well as the Manufacturing recovery plan[33]. Legislation plays a key role in increasing acceptance of 3D printing by introducing regulation, certification, standards and qualifications. Taking away the fear from end users to buy 3D printed products would be the desired outcome of such adjustments, and thus unleash the technological potential. Quality assurance is a large part of the reluctance, including the issues of liability towards end users, as information on the functionality, lifetime and reliability is not per se given. In addition, legislation could play a key role in encouraging the interoperability between systems, e.g. making interoperable printers, software (design and steering), which would further enable value chain interaction.

Fostering 3D printing uptake and growth. Key points to foster the uptake of 3D printing in the machine tool industry include the importance of rethinking the conventional supply chain (e.g. for the standard supply of rare or obsolete (spare) parts it is no longer required to stock these, opening up the opportunity to print these on demand, locally), as well as changing the mindset of designers to be bolder in the adoption while at the same time addressing the lack of skilled work force to support uptake. Initially, uptake can focus on low volume areas, and once accepted in these areas, then 3D printer suppliers can focus more and more on upscaling, for speed, interoperability and replicability.[34] While a strong legislation is needed to foster this, the entire value chain needs to be open to innovative and redesign current approaches to use 3D printing where its added value is highest. In this regard, additive manufacturing was identified in the Strategic Forum for Important Projects of Common European Interest (IPCEI) as the first of the additional value chains to be prioritised following the 6 selected value chains. Member States could take advantage of the opportunity to use the recommendations of the Strategic Forum for IPCEI and integrate them in their national recovery plans.

Sustainability potential and the digital transition. 3D printing as a technological solution has the possibility to contribute to the green transition while at the same time being engrained in the digital transition. 3D printing can increase resource efficiency, using only the needed materials for printing a strong, reliable part, while at the same time providing opportunities to shorten value chains, and reduce emissions from shipping, as well as shipping times, by localising production of e.g. spare parts and moulds that would otherwise be imported from countries like China. Beyond 3D printing, there are also further opportunities for the machine tool industry to support the green transition, such as with the use of second life machine tools, among others.

Digitisation of the supply chains, the development and availability of printable CAD files and a faster procedure for parts and process qualification can help companies to reduce their inventories, minimise cost (logistics and transport) and reduce the impact on the environment (less waste, lower CO_2 emissions). In particular, 3D printing can play a crucial role in increasing companies' sustainability and bringing the EU closer to achieve the targets set in the Circular Economic Action Plan. First, 3D printing has minimal shape and geometric constraints, allowing alternative optimised complex parts that have a lighter weight, enhanced durability and improved functionality. Second, 3D printing makes repair and remanufacturing easier and more cost-effective as spare parts can be printed on-demand and closer to

[32] https://ec.europa.eu/commission/presscorner/detail/en/ip_21_1682
[33] CECIMO. (2020b). CECIMO MANUFACTURING RECOVERY PLAN, https://www.cecimo.eu/publications/cecimo-manufacturing-recovery-plan/
[34] CECIMO. (2020a). INDUSTRIAL INNOVATION AFTER COVID-19: FOUR POINTS TO SUPPORT AM'S LONG-TERM GROWTH, https://www.cecimo.eu/publications/industrial-innovation-after-covid-19-four-points-to-support-ams-long-term-growth/

where they are needed. Hence, inventory waste and the carbon footprint of products is reduced while the lifetime of products requiring spare parts is extended.

4.2 Outlook

Europe as a leader in 3D printing for the machine tool industry. Europe is home to some of the most renowned machine tool industry stakeholders as well as being a stronghold for 3D printing expertise. Fostered correctly, bringing together these two worlds holds a great potential outlook for European industry, in pioneering both the technological and legislative frameworks to enable the uptake of 3D printing. Creating an innovation friendly regulatory framework would allow critical sectors such as the energy, construction, medical and aerospace sector to become more competitive and sustainable by rethinking their supply chains and enabling local productions of critical parts, hereby achieving strategic capacity in the development of critical goods.

Measuring sustainability. A means by which to communicate the benefits of 3D printing could be a certification or comparison of the CO_2 footprint, e.g. by developing a calculation method that takes into account emissions throughout the production cycle and perhaps beyond towards recycling, comparing 3D printing with subtractive techniques. This could serve to create further transparency on the possibilities, but also create acceptance, and could be fostered by standards or norms.

4.3 COVID-19

The COVID-19 crisis has put the 3D printing sector under the spotlight and focused the attention towards how to best exploit opportunities linked to the use of 3D printing e.g. enabling more localised and on-demand manufacturing that would bring Europe among the market leaders in this sector. The Product Watch report '3D printing of hybrid components' presents the COVID-19 impact on 3D printing especially with regard to ventilators. In response to the many questions received on 3D printed medical devices, the EC decided to publish a document 'Conformity assessment procedures for 3D printing and 3D printed products to be used in a medical context for COVID-19'. [35]

Here below we present an update on the latest developments and developments specific to the machine tool industry[36].

Operating below capacity. Machine tool companies have been considerably affected in their operations due to COVID-19 and were reported to be operating at upwards of 40% below capacity in the period of June 2020, and upwards of 50% below average in the period of March and April 2020, following the pandemic outbreak in Europe. In particular, activities related to machinery installation and servicing have been impacted.

Decreased consumption. Overall, and seeing also the recent decline in the industry as a whole, the European machine tool industry is expected to see an overall consumption decrease of roughly 25% in 2020 compared to 2019, taking into consideration the COVID-19 pandemic and its impact. That being said, rebound is expected in 2021 and 2022, though it may remain volatile, and recovery depends on a series of other factors (e.g. demand in other sectors, investment capacity and development of automotive markets).

Opportunities through COVID-19. Through the COVID-19 pandemic, certain opportunities are visible, e.g. for the industry to seek trajectories rooted in the digital and green transition, supported by stimulus packages and other emergency measures put forward by governments. Diversified supply chains, as well as exploring export markets will also form key reflections in the way forward post-COVID-19.

3D printing and prototyping. During COVID-19, 3D printing has been applied in the machine tool industry especially in support of rapid prototyping and quick response manufacturing. This was able to reduce delivery times on moulds or products prepared and shipped from China, which were delayed due to COVID-19. Along the same times, companies may also have preferred to print spare parts, preferring this than the long delivery times. This implied looking to 3D printing companies in a local context for supply, rather than from China or India. The longevity of these developments will only be visible once the pandemic has subsided. Once supply chains are running smoothly again, it can be expected that traditional manufacturing techniques will once again be preferred due to their lower costs.

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[35] European Commission. (2020a). Conformity assessment procedures for 3D printing and 3D printed products to be used in a medical context for COVID-19, https://ec.europa.eu/docsroom/documents/40562

[36] CECIMO. (2020d). CECIMO PRESS RELEASE: THE MANUFACTURING SECTOR IN THE COVID-19 CRISIS, https://www.cecimo.eu/news/cecimo-press-release-the-manufacturing-sector-in-the-covid-19-crisis/

Section 5

5. Annex

5.1 List of interviewees

Interviewee	Company	Country
Vincenzo BELLETTI	CECIMO	Belgium
Frédéric MELCHIOR	CECIMO	Belgium
Coen DE GRAAF	Province of North Brabant	The Netherlands
Ales HANCIC	Tecos - Slovenian Tool and Die Development Centre	Slovenia
Hannes FACHBERGER	Profactor	Austria

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About the ‘Advanced Technologies for Industry’ project

The EU’s industrial policy strategy promotes the creation of a competitive European industry. In order to properly support the implementation of policies and initiatives, a systematic monitoring of technological trends and reliable, up-to-date data on advanced technologies is needed. To this end, the Advanced Technologies for Industry (ATI) project has been set up. It provides policymakers, industry representatives and academia with

- Statistical data on the production and use of advanced technologies including enabling conditions such as skills, investment or entrepreneurship;
- Analytical reports such as on technological trends, sectoral insights and products;
- Analyses of policy measures and policy tools related to the uptake of advanced technologies;
- Analysis of technological trends in competing economies such as in the US, China or Japan;
- Access to technology centres and innovation hubs across EU countries.

You may find more information about the 16 technologies here: https://ati.ec.europa.eu.

The project is undertaken on behalf of the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the European Innovation Council and Small and Medium-sized Enterprises Executive Agency (EISMEA) by IDC, Technopolis Group, Capgemini, Fraunhofer, IDEA Consult and NESTA.

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