European Commission

September 2021

Advanced Technologies for Industry – Product Watch

3D printing of hybrid components

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

EUROPEAN COMMISSION

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 and Clusters
E-mail: GROW-ATI@ec.europa.eu

European Commission
B-1049 Brussels

Pdf ISBN 978-92-9460-824-6 doi: 10.2826/6144 EA-08-21-248-EN-N

Luxembourg: Publications Office of the European Union, 2021

September 2021

Table of contents

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

A key advanced manufacturing technology includes three-dimensional (3D) printing, also known as additive manufacturing. 3D printing is considered a highly innovative manufacturing solution with a great potential to revolutionise manufacturing and production globally. 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 of parts in various sectors. 3D printing is highlighted as a technology that is central to digital transformation, and part of the fourth industrial revolution - an Industry 4.0.[1]

3D printing is regarded as a high growth technology with revenues of €6.19 bn[2] recorded in 2017, an expected forecast of €13.31 bn in 2020 for all 3D printing products and services, globally.[3] By 2024 the revenue forecast is expected to reach upwards of €29.99 bn accordingly to the 2019 Wohlers Report – a highly anticipated report by 3D printing experts around the world. MarketsandMarkets Research[4] estimates the global 3D printing market size to be €8.34 bn ($9.9 billion) in 2018 and expect it to reach €29.32 bn ($34.8 billion) by 2024.

3D printing is relevant for a wide range of potential application areas and draws upon several technologies. The trend in the 3D printing applications is shifting from prototyping to functional part manufacturing in various verticals. Particularly relevant sectors include especially automotive, aerospace and health, as well as consumer goods, electronics, energy, industrial equipment and tooling, and construction, with varying degrees of maturity realised across these sectors.[5] Key factors for 3D printing include the interplay between quality, time, cost, size and volume. Depending on the targeted application area, varieties of materials can be applied, from plastics and ceramics, to metals and biomaterial, among others.[6]

---

[1] OECD. (2020). *The Digitalisation of Science, Technology and Innovation: Key Developments and Policies*

[2] All currencies are based on current exchange rate of 1€ = $US 1.18681, 7 September 2021

[3] McCue, T. (2019, March 27). Significant 3D Printing Forecast Surges to $35.6 Billion. Retrieved February 2020, from Forbes: https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#1e9924037d8a

[4] https://www.marketsandmarkets.com/Market-Reports/3d-printing-market-1276.html

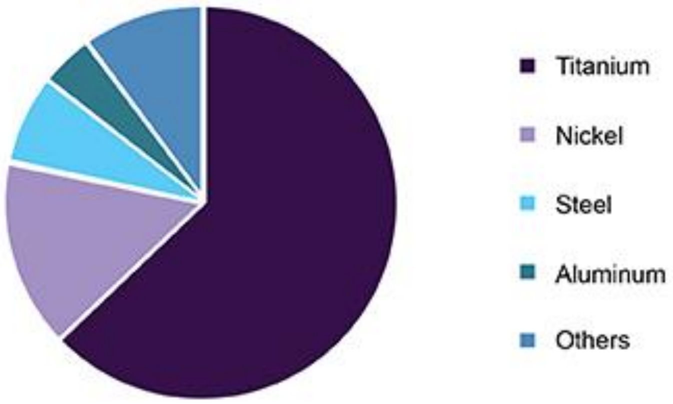
[5] TWI et al. (2017). A STRATEGIC APPROACH TO INCREASING EUROPE'S VALUE PROPOSITION FOR ADDITIVE MANUFACTURING TECHNOLOGIES AND CAPABILITIES: D2.1 Selection of Key AM Sectors for Europe.

[6] OECD. (2017). "3D printing and its environmental implications", in The Next Production Revolution: Implications for Governments and Business.

The use of metal powders for 3D printing is highlighted as one of the fastest growing areas of 3D printing and is considered as 'reaching the industrialisation stage'.[7] The area of metal 3D printing has seen another increase in the period from 2017 to 2018[8], following the considerable (80%) increase in systems sold between 2016 and 2017[9] and high growth rates for 3D printers.[10] In 2017, the 3D Metal Market was valued at €281.77 bn[11], with a Compound Annual Growth Rate (CGAR) of 31.8% from 2017 to 2025.[12] Taking into consideration current market trends, by 2029 the metal 3D printing value chain is expected to achieve a value of €16.01 bn.[13]

This report focuses on the 3D printing of metals as it is a stronghold in Europe, with many players situated in Germany, France, Italy and Sweden. Recent developments, including the increase of new equipment and machinery has reduced costs for printers, introducing also new technologies to tackle the barriers related to cost, quality, time and materials. Typical printer types for metal 3D printing including Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), Directed Energy Deposition (DED) and Binder Jetting.[14] EOS for example, headquartered in Germany, is one of the world leaders in the field of DMLS. The global share of metals used for 3D printing is dominated by titanium, followed by nickel, steel and aluminium, among others, as presented in Figure 1.

Figure 1: Global 3D printing metal market share by product



Source: Grand View Review, 2019

The carbon fibre market has experienced considerable growth, which is expected to continue. The market for carbon fibre reinforced plastics, as a composite material, has experienced considerable, double digit growth in recent years, as presented in Figure 2.[15] Carbon

[7] Roland Berger. (2018). Advancements in metal 3D printing Beyond powder bed – Additive manufacturing on the brink of industrialization.

[8] McCue, T. (2019, March 27). Significant 3D Printing Forecast Surges to $35.6 Billion. Retrieved February 2020, from Forbes: https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#1e9924037d8a

[9] McCue, T. (2018, June 04). Wohlers Report 2018: 3D Printer Industry Tops $7 Billion. Retrieved from Forbes: https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#4b12b5fc2d1a

[10] BCG. (2017, April 5). Get Ready for Industrialized Additive Manufacturing. (Boston Consulting Group) Retrieved 02 2020, from Boston Consulting Group: https://www.bcg.com/publications/2017/lean-manufacturing-industry-4.0-get-ready-for-industrialized-additive-manufacturing.aspx

[11] All currencies are based on current exchange rate of 1€ = $US 1.18681, 7 September 2021

[12] Grand View Research. (2019, January). 3D Printing Metal Market Size, Share & Trends Analysis Report By Form (Filament, Powder), By Product (Steel, Titanium, Nickel), By Application (Medical, Aerospace & Defence), And Segment Forecasts, 2019 - 2025. Retrieved from Grand View Research: https://www.grandviewresearch.com/industry-analysis/3d-metal-printing-market

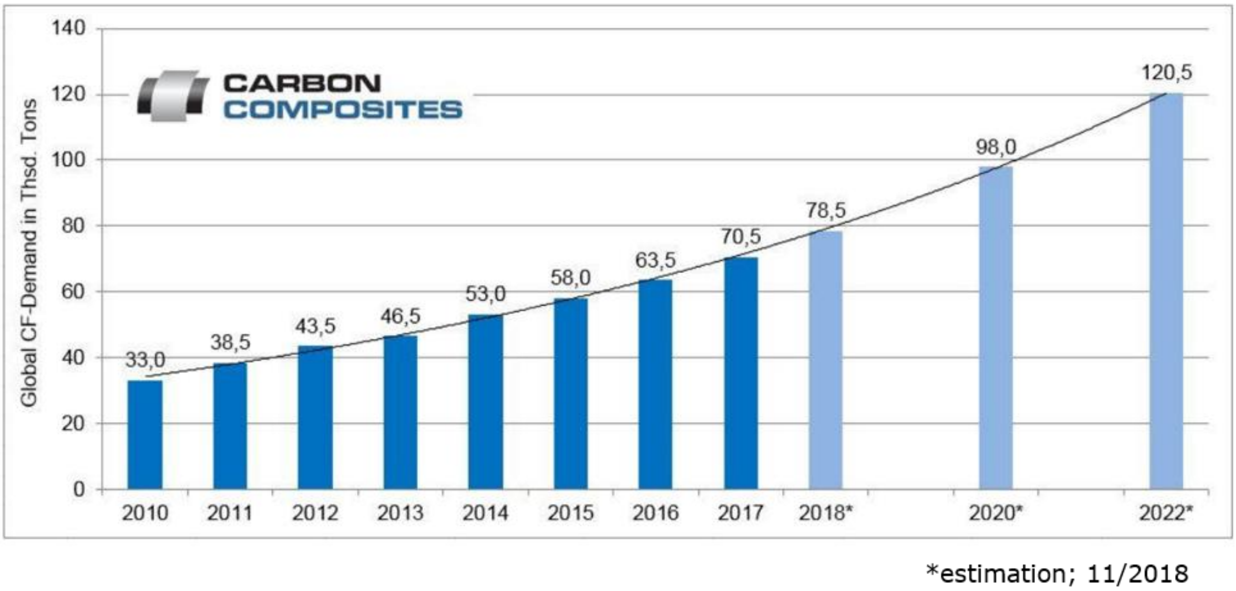
[13] IDTechEx. (2019). 3D Printing of Metals 2019-2029. IDTechEx Research.
Jason Dawes, R. B. (2015). Introduction to the Additive Manufacturing Powder Metallurgy Supply Chain. Johnson Matthey Technol. Rev., 243-256.

[14] IDTechEx. (2019). 3D Printing of Metals 2019-2029. IDTechEx Research.
Jason Dawes, R. B. (2015). Introduction to the Additive Manufacturing Powder Metallurgy Supply Chain. Johnson Matthey Technol. Rev., 243-256.

[15] AVK and CCeV. (2018, November). Market developments, trends, outlooks and challenges. Retrieved from Composites Market Report 2018: https://www.avk-tv.de/files/20181115_avk_ccev_market_report_2018_final.pdf

fibre is particularly relevant for light weighting, which is centrally important to the automotive industry in order to reduce emissions from fuel consumed. Mixing with hybrid metals can ensure that carbon fibres or other reinforced polymers are able to contribute to light weighting while maintaining structural stability. Typically, carbon fibre and carbon fibre composites are used for structural components such as exterior body parts, hoods, bonnets, and test plates, however in combination with hybrid materials.[16]

Figure 2: Evolution of the global demand for Carbon Fibre



Source: AVK and CCeV, 2018

We zoom in on the specific value chain '3D printing of hybrid components' including metal 3D printed structural components. Currently, particularly in the automotive sector, hybrid metal-composite applications are being developed with conventionally manufactured metal parts. In these cases, the metal inserts are considerably heavy with an often-suboptimal interface between the metal and polymer parts. Costs for the optimisation of the parts for their intended use are high due to the need for additional machining to reduce weight and increase the surface area for integration. Additional applications within the automotive sector can include interior and exterior components, structural elements, and powertrain parts, typically where an interface between polymers and metals can be found.[17] Parts combining 3D printed metals with reinforced polymers, or other materials, such as plastics, have a great potential to tackle industrial challenges such as light weighting, reducing costs and improving part performance, especially for sectors such as automotive, but also aerospace and beyond. The resulting advantages of the specific hybrid 3D printed metal and polymer products include[18]:

- A high stiffness/density ratio
- Weight reduction from 10% to 50% compared to traditional metal parts
- Smooth stress and strain transfer at the interface between the metal and polymer surfaces using optimised interface geometry, e.g. 3d printed inserts can be network-shaped with voids to be infiltrated by the polymer or composite, which will in turn enhance the strength of the interface
- Design for very high damping through increased surface of the interface and optimised network structure topology
- Improved global safety through tailored crash behaviour

[16] Vanguard Initiative '3DP Pilot'. (2020). Pilot action on Interregional innovation projects - Business Plan 'Hybrid 3DP-Carbon Fiber component for Blowers'. Brussels: European Commission

[17] Vanguard Initiative '3DP Pilot'. (2020). Pilot action on Interregional innovation projects - Business Plan 'Hybrid 3DP-Carbon Fiber component for Blowers'.

[18] Vanguard Initiative '3DP Pilot'. (2020). Pilot action on Interregional innovation projects - Business Plan 'Hybrid 3DP-Carbon Fiber component for Blowers'.

1.2 Objectives of this report

While 3D printing of hybrid components represents a niche market, it entails interesting insights for the deployment and commercialisation of 3D printed products. The value chain of metal 3D printing hybrid components entails many SMEs that are interested in developing 3D printing-based applications, but an increasing degree of maturity and automation of post processing is needed to stimulate the uptake of 3D printing technologies.

The report aims to provide an overview of relevant stakeholders to see how ATI based products can help EU industry to stay ahead of global competition. The objective is to map the key players in the metal 3D printing value chain, as well as to identify their strengths and weaknesses. Analyses were based on desk-research, interviews as well as on the internal expertise of IDEA Consult in the subject.

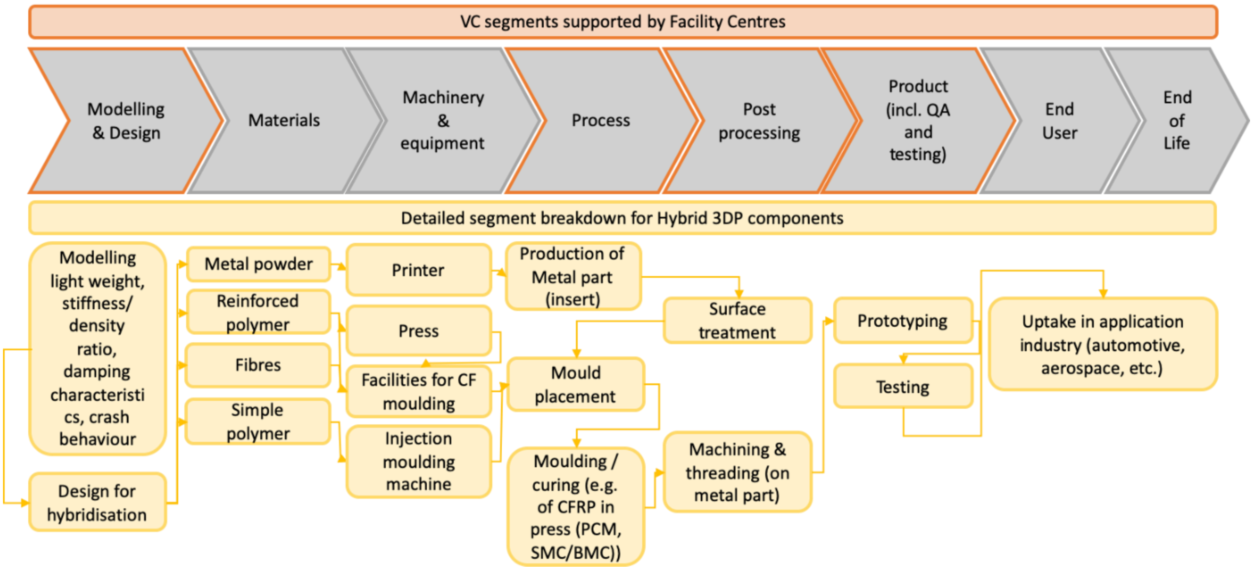
Section 2

2. Value chain analysis

2.1 Value chain structure

3D printing represents a dynamic and disruptive technology that is a key component in the digitalisation of industry and the transformation to Industry 4.0. The value chain structure can be outlined into key segments as depicted in Figure 3, with broad segments indicated in grey, and detailed indications related specifically to the 'metal 3D printing hybrid components' value chain.

Figure 3: The 3D printing value chain with detailed segments for the metal 3D printing of hybrid components[19].



Source: IDEA Consult, adapted from TWI et al., 2017 and Vanguard Initiative '3DP Pilot', 2020

In the 3D printing value chain, modelling and design are considered key initial steps to determine the development of the final product or a specific application area. In turn, the design determines the materials that should be selected for the specific application, as different metals bear different properties, and likewise simple and reinforced polymers have their own specific traits. Similarly, the design and materials determine the choices for machinery and equipment needed to manufacture the specific product, such as printers, presses and other material and application specific machines. The subsequent value chain segments target the processing, i.e. the manufacturing of the part, and the post-processing, such as surface treatment. Resulting from the process is a specific product, which will need to undergo a specific quality assessment (QA) and testing before being sent to the end user. An important segment at the end of the value chain is also the end of life, which should be equally reflected in the modelling and design phases at the onset, taking into consideration elements such as material choice and recyclability of 3D printed products.

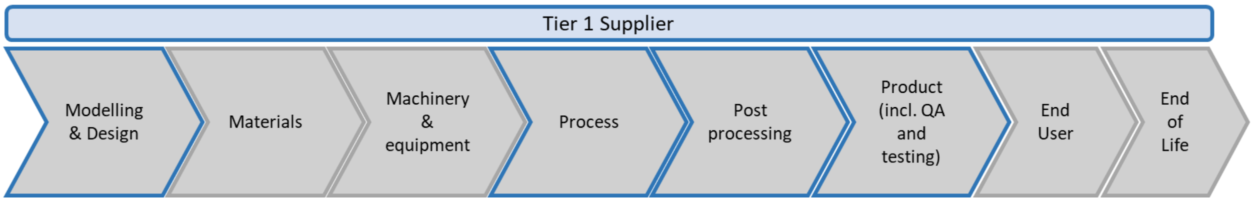
[19] In grey are the broad value chain segments, accompanied by the detailed segments in yellow. Highlighted in orange are the current segments supported by facility centres.

For hybrid components using 3D printing metal parts, the value chain consists of the following, more granular, steps[20]:

- Modelling for light weighting, stiffness, density ratio, damping characteristics, crash behaviour, among others
- Design for the hybridisation of the part
- Selection of materials in line with modelling and design requirements
- Acquisition of machinery and equipment in line with design and modelling requirements as well as chose materials
- Production of metal part (insert)
- Surface treatment of the metal part
- Placement of the part in the mould
- Moulding / curing of the part (e.g. in the Carbon Fibre Reinforced Polymer (CFRP) press
- Machining and threading (when needed, typically only on the metal)
- Resulting prototype
- Testing
- Uptake for the target application

At present, for the specific value chain indicated, facility centres (including Research and Technology Organisations (RTOs)) play an important role in supporting the development of the indicated value chain segments in transitioning from technology readiness level (TRL) 6-7 onwards towards commercial product. Once the initial design, prototyping, moulding, testing and validation are demonstrated, the supplier or relevant company will internalise the indicated segments, as shown in blue in Figure 4.

Figure 4: Specific value chain segments that will be taken over by the supplier (e.g. Tier 1) following support from a Facility Centre



Source: IDEA Consult, adapted from TWI et al., 2017

2.2 Key actors in the value chain

A series of key actors are essential in the realisation of the value chain, both in its present form with technology of the proposed value chain between TRL 6-7, as supported by facility centres, and in its commercialised form with suppliers. These key stakeholders include machinery and equipment manufacturers, materials suppliers, service providers and facility centres. The following section details the role of these key actors in the metal 3D printing hybrid components value chain and maps main stakeholders (non-exhaustive) in the tables below.

Machinery and equipment manufacturers have a central role in the realisation of 3D printed parts as the technology of the printer determines the parts that can be manufactured, as well as the size, quality and cost thereof. Table 1 presents a list of main players in the metal 3D printing manufacturing segment of the value chain. Machinery and equipment manufacturers are also known to be active in other roles and value chain segments, leading to a wider role as 'Industrial system manufacturer'.

[20] Vanguard Initiative '3DP Pilot'. (2020). Pilot action on Interregional innovation projects - Business Plan 'Hybrid 3DP-Carbon Fiber component for Blowers'.

Table 1: Main players in the metal 3D printing value chain – printer manufacturers organised by dominant technology

3D printer manufacturer	Specific 3D printing technology	Location	Website
3D System[21]	Powder Bed Fusion (PBF), Stereolithography (SLA)	United States	https://www.3dsystems.com/about-us
AddUp[22]	Powder Bed Fusion (PBF), Laser Beam Melting (LBM)	France	https://www.addupsolutions.com
EOS	Powder Bed Fusion (PBF), Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS)	Germany	https://www.eos.info/en
Concept Laser GmbH[23]	Powder Bed Fusion (PBF), Laster Sintering	Germany	https://www.ge.com/additive/de/who-we-are/concept-laser
Arcam AB[24]	Powder Bed Fusion (PBF), Electron Beam Melting (EBM)	Sweden	https://www.ge.com/additive/who-we-are/about-arcam
SLM Solutions	Powder Bed Fusion (PBF), Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS)	Germany	https://www.slm-solutions.com
DMG Mori[25]	Powder Bed Fusion (PBF), Direct Metal Laser Sintering (DMLS)	Germany / Japan	https://en.dmgmori.com
Renishaw	Powder Bed Fusion (PBF)	United Kingdom	https://www.renishaw.com/en/metal-3d-printing--32084
Sisma	Powder Bed Fusion (PBF), Laser Metal Fusion (LMF)	Italy	https://www.sisma.com/en/
Trumpf	Powder Bed Fusion (PBF), Laser Metal Fusion (LMF)	Germany	https://www.trumpf.com/en_INT/
Aconity3D	Powder Bed Fusion (PBF), Laser powder bed fusion	Germany	https://aconity3d.com
Matsuura	Powder Bed Fusion (PBF)	Japan	https://www.matsuura.co.jp/english/
Velo3D	Powder Bed Fusion (PBF)	United States	https://www.velo3d.com
Aurora Labs	Powder Bed Fusion (PBF), Direct	Australia	https://www.auroralabs3d.com

[21] Purchased French printing brand Phenix Systems in 2013 to expand metal 3D printing expertise
[22] Joint Venture between Michelin and Fives
[23] Acquired by General Electric in 2016
[24] Under acquisition by General Electric, initially announced in 2016
[25] A joint German Japanese company (name DMG Mori Seiki in Japan)

3D printer manufacturer	Specific 3D printing technology	Location	Website
	Energy Deposition (DED)		
Optomec	Direct Energy Deposition (DED)	United States	https://optomec.com
Sciaky	Direct Energy Deposition (DED), Electron Beam Additive Manufacturing (EBAM)	United States	https://www.sciaky.com
BeAM	Direct Energy Deposition (DED)	France	https://www.beam-machines.com
InnsTek	Direct Energy Deposition (DED), Direct Metal Tooling (DMT)	South Korea	http://www.insstek.com
Desktop Metal	Material Extrusion, Metal Injection Moulding (MIM)	United States	https://www.desktopmetal.com
Markforged[26]	Material Extrusion, Metal Injection Moulding (MIM)	United States	https://markforged.com
HP Metal Jet	Other technology; binder and metal powder	United States	https://www8.hp.com/us/en/printers/3d-printers/products/metal-jet.html
Digital Metal[27]	Other technology; based on Binder Jetting	Sweden	https://www.hoganas.com/en/services/digital-metal/
ExOne	Other technology; Binder Jetting with industrial materials	Germany	https://www.exone.com
XJet	Other technology; NanoParticle Jetting technology	Israel	https://www.xjet3d.com
Vader Systems[28]	Other technology; similar to material jet process	United States	https://www.xerox.com/en-us/innovation/insights/additive-manufacturing-3d-printing
Pollen AM	Other technology; Indirect metal manufacturing process with Metal Injection Moulding (MIM)	France	https://www.pollen.am
Exxadon[29]	Other technology linking with nanotechnology	Switzerland	https://www.exaddon.com
ADMATEC	Other technology; Digital Light Processing	The Netherlands	https://admateceurope.com

Source: Based on 3Dnatives, 2019

[26] Coming from work with carbon fibres
[27] Acquired by Höganäs
[28] Acquired by Xerox
[29] Subsidiary of Cytosurge

Materials suppliers play a key role in that they have the responsibility to supply adequate materials for the targeted 3D printed product. Especially in the field of metal additive manufacturing, this means metal powders coming from raw materials. Several printer manufacturers offer integrated solutions of certified powders for the specific printers in order to guarantee powder quality. Technavio has identified the top five leading vendors in their global metal powders market 2017-2021 report namely Alcoa, ATI, BASF, Rio Tinto, and Sandvik.[30] A detailed list of metal powder manufacturers can be found in Table 2.

Table 2: A detailed list of metal powder manufacturers

Metal Powder Manufacturer for 3D printing	Location	Website
A3DM Technologies	United States	https://www.a3dm.com/
Advance Powder and Manufacturing	Canada	http://www.advancedpowders.com/
Advanced Metal Powders	Austria	https://www.amp-powders.com/
Aeromet International Ltd	United Kingdom	http://www.aeromet.co.uk/
Alcoa	United States	http://www.alcoa.com/
AMC Powders	China	http://www.amcpowders.com/
American Elements	United States	https://www.americanelements.com/quote
Argen	United States	http://www.argen.com/
Astro Alloys	United States	https://www.astroalloys.com/
ATI Specialty Materials	United States	https://www.atimetals.com/
BASF New Business	Germany	https://www.basf.com/
Beijing Bestpower Technology and Engineering	China	http://www.ibestpower.cn/
BIKAR-METALLE	Germany	http://www.bikar.com/
Bohler Edelstahl	Austria	https://www.bohler-edelstahl.com/
BSS Additive	United States	https://www.barnstormstudio.com/
C. Hafner	Germany	http://www.c-hafner.de/
CNPC Powder	Canada	http://www.cnpcpowder.com/
Cogne	Italy	http://www.cogne.com/
Cooksongold	United Kingdom	http://www.cooksongold.com/
Elementum 3D	United States	https://www.elementum3d.com/
Equispheres	United States	https://equispheres.com/
Exmet AB	Sweden	http://www.exmet.se/
Fabian Werth/Werth Metal	Germany	https://www.pyropowders.de/
Falcontech	Japan	http://www.falcontech.com.cn/
GKN Hoeganaes	United States	http://www.gkn.com/hoeganaes
Global Advanced Metals	United States	https://www.globaladvancedmetals.com/
HC Stark	Germany	http://www.hcstarck.com/
Hilderbrand	Switzerland	http://www.hilderbrand.ch/

[30] Business wire. (2020). Top 5 vendors int he global metal powders market from 2017 to 2021: Technavio. Retrieved February 2020, from Business Wire: https://www.businesswire.com/news/home/20170724006279/en/Top-5-Vendors-Global-Metal-Powders-Market

Metal Powder Manufacturer for 3D printing	Location	Website
Hoganas	Sweden	https://www.hoganas.com/
JAMPT	Japan	https://www.jampt.jp/
Kanthal Additive Manufacturing	Sweden	https://www.kanthal.com/en/products/kanthal-additive-manufacturing/
Kennametal	United States	https://www.kennametal.com/
Legor Group S.P.A	Italy	http://www.legor.com/en
LPW Technology	United Kingdom	http://www.lpwtechnology.com/
LSN Diffusion	United Kingdom	http://lsndiffusion.com/
MD Alloys	United Kingdom	http://www.mdalloys.com/
Metasphere Technology	Sweden	http://www.metasphere.se/
Mimete	Italy	http://www.mimete.com/
Molyworks	United States	https://www.molyworks.com/
Nanosteel	United States	http://www.nanosteelco.com/
Polema	Russia	http://www.polema-rus.com/
Powmet	Italy	http://www.powmet.it/
Progol3D	Italy	http://www.progol3d.com/
PyroGenesis Canada	Canada	http://www.pyrogenesis.com/
Raycham	China	http://en.raycham.com/
Rina	Italy	https://www.rina.or/
Rosswag Engineering	Germany	https://www.rosswag-engineering.de/
RTMP (Rio Tinto Metal Powders)	Canada	http://qmp-powders.com
Sandvik	Sweden	http://smt.sandvik.com/
Shanghai Blue Cast Special Alloy Material	China	http://www.superalloys.com.cn/AboutSt/gsjs.html
Sri Kaliswari Metal Powders	India	http://www.sri-kaliswari.in/
Stanford Advanced Materials	United States	http://www.samaterials.com/
Tekna	Canada	http://tekna.com/
Toyal Europe	France	http://toyal-europe.com/us/home.php
US Metal Powders	United States	http://www.usmetalpowders.com/
Valimet	United States	http://valimet.com/
VDM Metals	Germany	https://www.vdm-metals.com/en/
Veloxint	United States	http://www.veloxint.com/
Voestalpine	Austria	http://www.voestalpine.com/
We Are Aerospace	France	https://www.weare-aerospace.com/en/additive/
Z3DLab	France	http://z3dlab.com/

Source: 3D Printing Business Directory, 2019

Service providers (also referred to as service bureaus) are specific companies specialised in supporting the development of 3D printed parts by offering modelling, design and manufacturing of the requested 3D printing as a service. They have a team of experts that have the capacity to carry out orders as needed. For example, Materialise Software provides companies with a platform of software tools that manage and control the 3D printing process more efficiently.[31] Also, Stratasys provides smart software integrations systems to their clients.[32] A list of the top 3D printing service providers for metal additive manufacturing are found in Table 3. Service providers can also serve to explore the 3D printing business model, with initial orders prior to the acquisition of large machines.

Table 3: Top 3D printing service providers for metal 3D printing, globally

3D printing service provider	Type	Location	Website
	3D printing service	Belgium	https://i.materialise.com/en
Kraftwurx	3D printing service	United States	http://www.kraftwurx.com/
Materialise OnSite	3D printing service	Belgium	https://www.materialise.com/en/manufacturing/materialise-onsite
Shapeways	3D printing service	United States	https://www.shapeways.com/
Sculpteo	3D printing service	France	https://www.sculpteo.com/en/
3Diligent	On-demand manufacturing platform	United States	https://www.3diligent.com/
3D Hubs	On-demand manufacturing platform	Netherlands	https://www.3dhubs.com/
3ERP	On-demand manufacturing platform	China	https://www.3erp.com/
Protolabs	On-demand manufacturing platform	United Kingdom	https://www.protolabs.co.uk/
SD3D	3D printing service	USA	https://www.aniwaa.com/buyers-guide/3d-printers/best-3d-printing-services/
Star Rapid	3D printing service	China	https://www.starrapid.com
Stratsys Direct	3D printing service	United States	https://www.stratasysdirect.com
Weerg	3D printing service	Italy	https://www.weerg.com/en/
Xometry	3D printing service	United States	https://www.xometry.com

Source: Cherdo, 2020

[31] Materialise. (2020). Materialise Software. Retrieved from Materialise: https://www.materialise.com/en/software
[32] Stratasys direct manufacturing. (2020). Manufactured parts on demand. Retrieved from Stratasys direct manufacturing: https://www.stratasysdirect.com

Facility centres are typically R&D&I organisations, such as universities, Research and Technology Organisations (RTOs) that support in the development and demonstration on the technological solution. Once demonstrated, a Tier 1 supplier will internalise the value chain segments supported by the facility centre. Facility centres will benefit from projects through learning, and better-connected networks, which will lead to technology spill overs for further companies. Many facility centres throughout Europe are active in the field of 3D printing, like Fraunhofer, TNO, UNIBO, VTT, Tecnalia, CEA, etc. A list of Facility centres that are active in the area of metal 3D printing and that have been mapped through the '3DP Pan EU Platform'[33] are presented in Table 4.

Table 4: Selection of Facility Centres that are active in the field of 3D printing

Organisation name	Location	Website
3D Activation	Germany	https://www.3d-activation.de/
3D Company - Divisione di Artedas Italia Srl	Italy	http://www.3dcompany.it/
3D Metal	Italy	https://3dmetal.it/
3DZ Brescia Srl	Italy	http://www.3dz.it/
Addimen Bizkaia SL	Spain	http://www.addimen.com/
Additive 3D	France	https://www.additive-3d.fr/
Additive Italia Srl	Italy	http://www.add-it.tech/
AIDIMME	Spain	http://www.aidimme.es/
AITIIP Technology Centre	Spain	http://www.aitiip.com/
Alma Mater Studiorum - Universita di Bologna	Italy	http://www.mam.unibo.it/en
Binder3D	The Netherlands	http://www.binder3d.com/
CEA	France	http://www.cea.fr/
CETIM	France	https://www.cetim.fr/en
CIRI MAM	Italy	http://www.mam.unibo.it/
Competence Industry Manufacturing 4.0	Italy	https://cim40.com/
FOTEC Forschungs und Technologietransfer GmbH	Austria	https://www.fotec.at/
FOURTH DIMENSION TECHNOLOGIES S.A.	Greece	https://4thdimension.gr/
Fraunhofer Project Center at the University Twente	The Netherlands	http://amcenter.eu/
Fundacio Eurecat Cerdanyola	Spain	https://eurecat.org/
Future Manufacturing Technologies	Finland	http://www.oulu.fi/fmt
GM Prod	France	https://www.fabrication-additive.com/
HES	Austria	https://hes.hirtenberger.com/en/
Hypermetal	Portugal	https://hypermetal.eu/
IDPro	Belgium	http://www.idpro.be/
IMA	Italy	https://ima.it/en/
Inegi	Portugal	http://www.inegi.pt/
INSA Lyon	France	https://www.insa-lyon.fr/en/
IPC Centre technique industriel de la plasturgie et des composites	France	https://ct-ipc.com/

[33] Brainport Development N.V. (2020) 3DP PAN EU Facility Centres. Retried from: https://3dppan.eu/facility-centres, on 15 April 2020

Organisation name	Location	Website
LEITAT	Spain	https://www.leitat.org/castellano/
Lino3D	Greece	https://lino3d.com/
Marhellabs	Germany	https://www.marhellabs.com/
Optimus 3D S.L.	Spain	http://www.optimus3d.es/
POLIMI	Italy	https://www.polimi.it/
ProM Facility/Trentino Sviluppo	Italy	http://www.promfacility.eu/
RHP-Technology GmbH	Austria	https://www.rhp-technology.com/en
Saxion University of Applied Sciences	The Netherlands	https://www.saxion.edu/business-and-research/research/smart-industry/industrial-design/industrial-design
SCAN&3DPRINT S.L.	Spain	https://www.scan-3dprint.com/
Silex 3D Print	France	https://silex3dprint.fr/
Tecnologia & Design s.c.a.r.l	Italy	http://www.tecnologiaedesign.it/
Tecos	Slovenia	https://www.tecos.si/en/
Triditive S.L.	Spain	http://www.triditive.com/
TUT	Finland	https://www.tuni.fi/fi
UNDO Prototipos S.L.	Spain	http://www.undoprototipos.com/

Source: 3DP Pan EU Platform Facility Centres

Original Equipment Manufacturer (OEM), in the automotive industry OEMs refer to car producers. In this context, OEM car producers are responsible for assembling components produced by suppliers, namely Tier 1 and Tier 2 suppliers, resulting in the final product.

2.3 Linkages along the value chain

Several types of collaboration between stakeholders along the 3D printing value chain can be identified. These include collaboration (i) to shorten time to market, (ii) for R&D purposes, related to materials, products, processes, etc. and (iii) to increase market access, with synergies between stakeholders along different value chain segments.[34] Furthermore, there are three types of companies that can be observed along the value chain, referring also to the key stakeholders indicated in the section above. These include companies that are focussed on a specific value chain segment and highly specialise in it, such as Hirtenberger that is specialised in post-processing and surface treatment technologies[35], and companies offering multiple services along several value chain segments, such as EOS, the printer manufacturer that sells certified metal powders for use with its own printers.[36] The latter can go so far as to be integrated solution providers offering a completed start-to-finish 3D printing service for companies.[37]

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 the area of metal structural components, mainly Tier 1 actors are

[34] 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.
[35] Hirtenberger. (2020). Hirtenberger engineered surfaces. Retrieved February 2020, from https://hes.hirtenberger.com/en/
[36] EOS. (2020). Materials for Metal Additive Manufacturing. Retrieved February 2020, from EOS: https://www.eos.info/material-m
[37] IDEA Consult. (2016). Study on Assessing innovation capability of EU companies in developing Advanced Manufacturing Technologies.

present across various segments of the entire value chain, creating new supply chains and production processes in their development. For example, the value chain for 3D printing for aircraft is highly integrated with Tier 1 and Tier 2 OEMs/suppliers present in segments from materials and software to final integration.

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 for an OEM.

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. Figure 5 depicts an overview of these key strengths, opportunities, challenges, and risks for the metal 3D printing of hybrid components value chain.

Figure 5: Strengths, opportunities, challenges and risks for the metal 3D printing of hybrid components value chain

Source: IDEA Consult

3.1 Strengths

Europe as a frontrunner for metal and hybrid 3D printing. Given Europe's competitive advantage in the field of metal 3D printing, it is important that Europe continues to lead innovation in this specific technology area of 3D printing, and maintains a competitive advantage as compared to the United States. Continued R&D&I remain important to keep this strength, as well as the search for appropriate business models and new market opportunities for 3D printing to continue along current project growth trends. Companies should remain active and follow the latest developments, including them in the planning and continued technological development of their solutions. Their approach should be structured, ideally through a technology roadmap and should have in its scope the entire 3D printing process.

Complex and custom parts. The design of complex parts remains the greatest strength for 3D printed hybrid parts. Aspects that may be considered as complex include grids, the overall topology, internal channels, and other parts that are considered to be non-conventional or customised. Through printing complex internal structures, a part can become more robust, while using less material. For instance, a blower, i.e. engine air inlet, can be manufactured based on a combination of 3D printed metal parts and CFRP using press shaped (Sheet Moulding Compounds – Prereg Compression Moulding (SMC-PCM)) technologies.[38] The result is a singular part, and with the optimal joint between both materials (replacing gluing technique). Through hybrid printing with CFRP, cost gains versus traditional CFRP methodology (Autoclave) are also

[38] Vanguard Initiative 3DP Pilot. (2020). *Pilot action on Interregional innovation projects - Business Plan 'Hybrid 3DP-Carbon Fiber component for Blowers'.* Brussels: European Commission

envisaged. Furthermore, strengths lie in combining the printing of complex parts in combination with high volume production, e.g. through the printing of complex 3D printed parts in steel, combining with aluminium casting for a steel-aluminium hybrid.

Light weighting. Hybrid parts show a lot of potential in their application for weight reduction of parts. Further light weighting is achieved with the use of CFRP. Through decreased weight of vehicles, such as cars, airplane parts, and even satellites, fuel efficiency is improved, with simultaneous reductions in energy consumption and thus carbon emissions (in the case of combustion engines). Examples of projects drawing on 3D printed and reinforced polymer parts include a lightweight robot (with 55% weight saving) containing 3D printed metal parts assembled to the shell and co-cured with CFRP, among others.[39]

3.2 Opportunities

Wider application areas for hybrid metal 3D printed and CFRP components. The value chain for metal 3D printed and CFRP hybrid parts focusses on the automotive sector, however hybrid material structural components based on 3D printed metals are relevant for other sectors such as aerospace, healthcare, consumer goods, machinery and tooling, among others. Target applications areas are those that are in need of light weighting, but also looking for structurally sound parts, which is evident through the growing market for carbon fibre as a whole. Parts that are currently using conventional techniques such as gluing plastics and metals are potential candidates for hybridisation. Specific areas of interest identified by interviewees include prostheses, sporting goods, such as bicycles, as well as robotics. A list (non-exhaustive) of application areas for which these types of parts could be of interest, together with indications on the specific parts, can be found in Table 5.

Table 5: Selection of identified application areas for 3D printed hybrid components with metal 3D printing and CFRP

Application areas	Type of hybrid part	Source
Robotics	3D printed metal parts assembled to the shell of a hydraulic quadrupled robot leg and co-cured with CFRP	Türk, Rüegg, Biedermann & Meboldt, 2019
Rotor blade	Hybrid additive manufactured rotor blade	Kaspar, Häfele, Kaldenhoff, Griebsch & Vielhaber, 2017
Motorcycle parts	Brake lever based on hybridised process with CFRP composite elements	Sher, 2018
Aircraft structures (fuselage and wing)	3D printed titanium fitting joined to CFRP plate through thermoforming and injection moulding	Gardiner, 2020
Aeronautics interior parts	3D printed metal honeycomb structures joined with CFRP to create aircraft instrument panel	Türk, Kussmaul, Zogg, Klahn, Spierings, Könen, Ermanni, Meboldt, 2016
Satellite parts	Metal part joined with CFRP to create a camera baffle for a satellite	Laboratory of Composite Materials and Adaptive Structures, 2014
Manufacturing equipment	Metal part joined with thermoplastic to create AM jig saw leg	Leutenecker, B., Klahn, C. and Meboldt M., 2015
Prosthetics	3D printed metal socket and pylon joined with CFRP to create prosthetic knee	Türk, Einarsson, Lecomte, Meboldt, 2018

Source: compiled by IDEA Consult

Other hybrids. A hybrid part in this report refers to a strict definition of a combined 3D printed metal and CFRP part. However, other forms of hybrid parts and processes also exist. Broadly

[39] Türk, D., Rüegg, F., Biedermann, M., & Meboldt, M. (2019). Design and manufacture of hybrid metal composite structures using functional tooling made by additive manufacturing. *Design Science, 5*(E16)

speaking, hybrids can refer to combinations of any two materials. These parts can be hybrids through their materials (mixing two materials together) or through their processes (printed and joined separately by a variety of means). Hybrids are found and can be applied in a wide range of sectors and application areas, and in some cases are already considered state of the art. For example, for moulding and tooling, 3D printing is considered state of the art for the printing of complex internal channels fused with standard parts or a hull. LEGO Group has over 20 years of experience in applying 3D printing[40] to develop complex internal injection moulds for LEGO blocks, which are hybridised with a standard simple outer shell. Further hybrids can be in the example of mixed hybrid materials, where two materials are printed at the same time. For example, 3D printing using dry, binder fibre, can be co-extruded with plastic, ceramic or metal matrix materials or print multiple materials to achieve a multifunctional structure such as rotor blades, aircraft wings, or other car parts (large surface areas).[41]

3.3 Risks

Raw materials. The most important metals for 3D printing are titanium, aluminium and magnesium. However, neither titanium nor magnesium primary raw materials are found within Europe. The strengths of Europe in metal 3D printing are therefore dependent on materials that are sourced outside of Europe. GKN additive announced in November 2019 that it will produce and store metal 3D printing powders in Europe to better address demand.[42] Recycling also boasts possibilities for Europe to secure the necessary resources. Especially for aluminium, Europe is a recycling leader. Specific sectors such as aerospace are working on recycling of titanium and other critical raw materials. This trend should be continued to be developed both in line with the development of a circular economy and to ensure the overall sustainability of 3D printing.

International competition: The United States & Asia. The United States is leading in terms of polymer printing, while Europe is leading in terms of 3D printing ceramic and metal. In the area of metal 3D printing, Europe has been in a competitively advantageous position, however this is set to change with United States companies increasing their presence in the metal 3D printing market, also through the acquisition of European players. For example, General Electric has acquired both ARCAM (Sweden) and Concept Laser (Germany) between 2016 and 2017. The 3D printing metal parts market is however spreading, as binder jetting is dominated by United States based players like HP, Desktop Metal, ExOne, GE, while laser-based technologies are dominated by EU players. It is thus important to ensure that European players are able to remain competitive in the global market, especially versus the United States. The Asian 3D printing market is projected to experience considerable growth after having been lagging in 3D printing adoption as compared to the Unites States and Europe in recent years. As a result of various actions, including a 2017 'Additive Manufacturing Industry Development Action Plan' China has made considerable investments including providing support to promising companies, supporting standardisation efforts and bringing 3D printers into schools.[43]

Brexit. The departure of the United Kingdom from the European Union also entails a risk as the United Kingdom is quite active and experienced in the area of 3D printing. Several United Kingdom based actors invested heavily in 3D printing equipment and knowledge. Brexit might result is a loss of manpower and capacity. The United Kingdom houses several 3D printing centres like Lancashire3D, 3DPrintUK, Protolabs, Print My Part, 3D Print Direct, etc. In addition, Renishaw is headquartered in Wotten-under-Edge, Gloucester and has over 40 years of

[40] White, A. (2018, September 15). *LEGO Brand Group Invests in ·d Printing Firm Evolve*. Retrieved from BricksFanz: http://bricksfanz.com/lego-brand-group-invests-in-3d-printing-firm-evolve

[41] Gardiner, G. (2018, January). *3D-Printed composite wind blades and aircraft, closer than you think.* Retrieved from https://www.compositesworld.com/blog/post/3d-printed-composite-wind-blades-and-aircraft-closer-than-you-think

[42] Essop, A. (2019, November 13). *GKN ADDITIVE TO LOCALLY PRODUCE AND DISTRIBUTE METAL 3D PRINTING POWDERS IN EUROPE*. Retrieved from 3D Printing Industry: https://3dprintingindustry.com/news/gkn-additive-to-locally-produce-and-distribute-metal-3d-printing-powders-in-europe-164735/

[43] AMFG. (2019, November 20). *AM Around the World: How Mature is 3D Printing in the Asia-Pacific Region?* Retrieved from https://amfg.ai/2019/11/20/am-around-the-world-how-mature-is-3d-printing-in-the-asia-pacific-region/

experience in the aerospace sector, with expertise in 3D printing metals. Lastly, Airbus, as a pan-European economic collaboration and key organisation that has worked on industrialising 3D printing processes also has over 5,000 employees at two United Kingdom-based sites.

3.4 Challenges

Lack of standardisation. In the global setting, Europe is lagging behind in terms of standardisation activities in the area of 3D printing. Many players ask for standardisation, but in Europe, it is difficult to acquire public money to engage in standardisation activities. In addition, a coordinated European effort in global comparison is limited. Where industry from the United States and Asia is well coordinated, European players are limited in their engagement. As a result, the United States and Asia are actively involved in setting the standards and technical methods to be established in the future. This could lead to an increased dominance of United States and Asian players, pushing for their technical methods. This would then constitute a missed opportunity for European players, especially those offering better technical solutions. A coordinated European effort would be beneficial bringing together the efforts of projects and local organisations in order to influence these global decisions.

Sustainability. Overall, the greatest environmental impacts resulting from 3D printing arise from energy consumption during production, printer choice, material choice as well as end use. Important considerations include design for recyclability, which is especially relevant in the case of hybrid materials. A straightforward approach to ensure the uptake and consideration of sustainability in the technologies for 3D printing is to align them with economic incentives.

Skills and Education. The issue of skills for 3D printing, especially also hybrid printing raises the question both for skills as well as education. There is a need for appropriate training modules, curricula and on the job training opportunities in order to enable 3D printing across fields. While engineers are generally aware of the technology, only one in ten can currently be convinced to take a deeper look into applying the technology in their field, according to one of the interviewees. Especially a high quality of education on 3D printing potential remains a challenge across all educational programmes.

Section 4

4. Conclusions & outlook

4.1 Conclusions

Improving the deployment of technology. 3D printing, especially of hybrid metal and CFRP components, presents the possibility to develop stronger, lighter, and more complex parts. However, 3D printing technologies are still underdeveloped and especially underdeployed in industrial processes and applications. There is a need to align activities and coordinate efforts in order to support emerging and future solutions, for example, by facilitating access to supporting infrastructure such as Facility Centres. In addition, cooperation along the value chain from design and modelling, to process and product development and the development of services and business models needs to be fostered. There is a need for instruments that enable and facilitate cross value chains and cross regional collaborations, allowing for combinations of expertise and equipment in order to develop new techniques and systems. The '3DP Pan EU Platform' focuses on precisely this effort, namely bringing together the demand and supply of 3D printing services through access to matchmaking tools. In addition, the platform supports a database of facility centres throughout Europe that provide quality services related to testing, validating, and certifying of 3D printed parts.

Furthermore, European coordination about standards is highlighted as a point of improvement. It will be important for European stakeholders to align their efforts and join forces in order to maintain a strong position in the development of standards, certifications processes and the associated regulation.

3D printing for new possibilities. 3D printing is not meant to replace conventionally produced parts, but rather targets the creation of new designs and to enable new ways of thinking in production. In order to enable the uptake of 3D printing in wider application areas, education and '3D printing thinking' are needed. Education of engineers and designers and the development of appropriate business models remain essential points to tackle in order to unlock '3D printing thinking' and open the vast possibilities that can be achieved. Thus, the subject of 3D printing skills presents an important opportunity for European education institutes to align their work and develop common frameworks to support the development of 3D printing skills.

Sustainability. The European Green Deal presents a roadmap to make Europe the first climate-neutral continent. Sustainability issues such as resources efficiency, and reduction of energy consumption are key to achieving this goal. Through the proposed 3D printed hybrid components, resource efficient and light weight parts can be produced, contributing to reduced resource and fuel consumption and emissions reductions. It remains important that 3D printing take into consideration the potential it has, to contribute to the European Green Deal objectives. At the same time, it is important to consider end of life and recyclability of hybrid components, especially in cases where two material can no longer be separated and thus are not recyclable. The end of life of 3D printed products, but especially hybrid products remains especially important and should be taken up as an essential point in training and skills development for 3D printing. By incorporating sustainability in the technology education, designs can ensure to be sorted, and recycled to enable the sustainability and circularity of 3D printed parts.

Deglobalisation. As highlighted in the New Industrial Strategy for Europe,[44] 3D printing presents localisation or deglobalisation as an opportunity to locally produce parts and relocate certain elements of production to Europe. The importance of deglobalisation is becoming more

[44] European Commission (2020) 102 final. A New Industrial Strategy for Europe. Retrieved from: https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf

and more evident in view of the current COVID-19 pandemic, where 3D printing plays an increasingly important role. By interconnecting stakeholders and capacity, such as through the '3DP Pan EU Platform COVID-19 Matching',[45] Europe is able to respond to the current crisis in a coordinated fashion.

4.2 Outlook

The huge potential of 3D printing. In the current COVID-19 global pandemic, existing supply chains are under pressure and in some cases unable to adequately respond to demand. In this setting, 3D printing technologies have a huge potential for many industrial applications in various industries. For example, specialised 3D printing companies can produce 3D printed plastic and/or metal parts that can be added to the existing supply chains, helping them deliver higher numbers of components and inserts to assembly lines for the assembly of e.g. ventilators. Those 3D printing companies can also print specific, highly customised parts such as thinner respiratory tubes, nasal tubes or endotracheal tubes for the elderly. The potential of 3D printing in a deglobalised world is vital for European competitiveness as 3D printing allows to decentralise the production capacity.

European competitiveness requires fostering and strengthening the existing position. European companies have benefitted from the political commitment to advance the technological development in the area of 3D printing in Europe, which has allowed Europe to become a frontrunner in the area of metal and hybrid 3D printing. There is need to increase the maturity of several 3D printing technologies in order to widen both their industrial uptake as well as their application areas.

4.3. COVID-19 and 3D printer ventilators

Given today's COVID-19 pandemics, existing supply chains and manufacturing infrastructures for the production and delivery of adequate medical devices and equipment (in particular ventilators) are under heavy pressure. In that context, 3D printing does not have the production speed of other manufacturing technologies such as injection molding, but it nevertheless can represent a substantial complement to current production facilities, this in at least two ways. On the one hand, specialised 3D printing companies can produce 3D printed plastic and/or metal parts that can be added to the existing supply chains, helping them deliver higher numbers of components and inserts to assembly lines for the assembly of e.g. ventilators. Those 3D printing companies can also print specific, highly customised parts such as thinner respiratory tubes, nasal tubes or endotracheal tubes for the elderly. They can also supplement existing production facilities to produce plastic protective equipment for health professionals or print specific spare parts for ventilators, expanding rapidly and smoothly ('on request') the life cycle of ventilators. For instance some 3D printing companies already produce medical devices in Europe: Materialise (Belgium, Louvain) for instance is scaling up production capacity for valves to control oxygen flow from ventilators or face shields with ten transparent visors included.[46] Hewlett-Packard (HQ in Barcelona) launched a large production programme to scale up own production capacity of medical equipment, together with many others actors of the Catalan 3D printing Community such as Eurocat and Leitat.[47]

---

[45] 3DP PAN EU. (2020). *COVID-19*. Retrieved from https://3dppan.eu/covid-19-matching
[46] https://www.materialise.com/en/3d-printing-response-to-covid-19
[47] http://3dcovid19.tech/

On the other hand, many companies in other sectors have already embraced 3D printing as additional and complementary production technology, such as large automotive companies. The SEAT production facility of Barcelona, for instance, has launched a production programme to manufacture ventilators using 3D printing. The SEAT manufacturing unit should reach a production capacity of 300 ventilators per week in two weeks' time.[48] Some Catalan producers of swimming-pools, using 3D printing to print some specific parts, have also adjusted part of their manufacturing capacity to produce protective equipment for health workers. It is important to mention that all those initiatives have been certified by regional and national health authorities, and the certification protocols could be shared widely across Europe.

Another advantage of 3D printing is that production capacity is also easily decentralised and replicated by nature: 3D printers could be operating in companies, hospitals or other locations while being connected and managed remotely. Design files and scans can be shared between printers and location to produce e.g. protective equipment or spare parts 'in situ' or relatively closed to the affected areas, minimizing delivery times, etc.

Europe is a key player in 3D printing and some regions such as Catalonia, Flanders, South-Netherlands (Eindhoven region) can be considered as world-class hot spots in additive manufacturing. Networking and connecting these 3D printing facilities may help increase the production of some medical equipment and devices, and there is an urgent need to connect such players and to further scale up their production capabilities. Therefore, use could be made of pan-European 'matching platforms' such as the EU-funded '3D printing Pan-European Demonstration Platform'.[49]

[48] https://www.expansion.com/empresas/motor/2020/04/02/5e860031e5fdeaf02c8b459b.html
[49] https://3dppan.eu/covid-19-matching

Section 5

5. Annexes

5.1 List of interviewees

Interviewee	Company	Country
Claus Aumund-Kopp	Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM	Germany
Luca Raimondi	University of Bologna (Unibo)	Italy
Luca Tomesani	University of Bologna (Unibo)	Italy
Aleš Hančič	TECOS	Slovenia
Julien Bajolet	IPC	France

5.2 Bibliography

3D Printing Business Directory. (2019). *Metal Powder Manufacturer*. Retrieved February 2020, from 3D Printing Business Directory: https://www.3dprintingbusiness.directory/company-category/metal-powder-manufacturer/

3Dnatives. (2019, September 2). *A Comprehensive List of all the Metal 3D Printer Manufacturers*. Retrieved from 3Dnatives - your source for 3D printing: https://www.3dnatives.com/en/metal-3d-printer-manufacturers/

3DP PAN EU. (2020). *COVID-19*. Retrieved from https://3dppan.eu/covid-19-matching.

AMFG. (2019, November 20). *AM Around the World: How Mature is 3D Printing in the Asia-Pacific Region?* Retrieved from https://amfg.ai/2019/11/20/am-around-the-world-how-mature-is-3d-printing-in-the-asia-pacific-region/.

AVK and CCeV. (2018, November). *Market developments, trends, outlooks and challenges.* Retrieved from Composites Market Report 2018: https://www.avk-tv.de/files/20181115_avk_ccev_market_report_2018_final.pdf

BCG. (2017, April 5). *Get Ready for Industrialized Additive Manufacturing*. (Boston Consulting Group) Retrieved 02 2020, from Boston Consulting Group: https://www.bcg.com/publications/2017/lean-manufacturing-industry-4.0-get-ready-for-industrialized-additive-manufacturing.aspx

Brainport Development N.V. (2020, April 15). *3DP PAN EU Facility Centres*. Retrieved from https://3dppan.eu/facility-centres.

Business wire. (2020). *Top 5 vendors int he global metal powders market from 2017 to 2021: Technavio*. Retrieved February 2020, from Business Wire: https://www.businesswire.com/news/home/20170724006279/en/Top-5-Vendors-Global-Metal-Powders-Market

Cherdo, L. (2020, February 6). *THE 10 BEST 3D PRINTING SERVICES IN 2020 (ON-DEMAND MANUFACTURING)*. Retrieved February 2020, from ANIWAA: https://www.aniwaa.com/buyers-guide/3d-printers/best-3d-printing-services/

CIKONI. (2020). *AdditiveCARBON – Hybridization of 3D printing with carbon fibers*. Retrieved February 2020, from CIKONI composites innovation: https://cikoni.com/en/engineering-for-additive-manufacturing-and-bionic-design

Davies, S. (2019, November 13). *GKN Additive to produce metal additive manufacturing powders in Europe*. Retrieved from tctmagazine: https://www.tctmagazine.com/3d-printing-news/gkn-additive-produce-metal-additive-manufacturing-europe/

EOS. (2020). *Materials for Metal Additive Manufacturing*. Retrieved February 2020, from EOS: https://www.eos.info/material-m

Essop, A. (2019, November 13). *GKN ADDITIVE TO LOCALLY PRODUCE AND DISTRIBUTE METAL 3D PRINTING POWDERS IN EUROPE*. Retrieved from 3D Printing Industry: https://3dprintingindustry.com/news/gkn-additive-to-locally-produce-and-distribute-metal-3d-printing-powders-in-europe-164735/

European Commission. (2014). *Additive manufacturing in FP7 and Horizon 2020 Report from the EC workshop on additive manufacturing : Brussels, 18 June 2014.* Retrieved from https://op.europa.eu/en/publication-detail/-/publication/6aeec19c-265f-11e7-ab65-01aa75ed71a1

European Commission. (2018, February 22). *Additive manufacturing.* Retrieved from https://ec.europa.eu/research/industrial_technologies/pdf/additive_manufacturing_factsheet_2018.pdf

European Commission. (2018). *Report on Critical Raw Materials and the Circular Economy.* Luxembourg: Publications Office of the European Union.

European Commission. (2020). *A New Industrial Strategy for Europe.* Brussels: European Commission. Retrieved from https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf

Gardiner, G. (2018, January). *3D-Printed composite wind blades and aircraft, closer than you think.* Retrieved from https://www.compositesworld.com/blog/post/3d-printed-composite-wind-blades-and-aircraft-closer-than-you-think

Gardiner, G. (2020, March). *Premium AEROTEC demonstrates hybrid CFRP-AM metal design for future lightweight aircraft structures*. Retrieved from https://www.compositesworld.com/news/premium-aerotec-demonstrates-hybrid-cfrp-am-metal-design-for-future-lightweight-aircraft-structures

Grand View Research. (2019, January). *3D Printing Metal Market Size, Share & Trends Analysis Report By Form (Filament, Powder), By Product (Steel, Titanium, Nickel), By Application (Medical, Aerospace & Defense), And Segment Forecasts, 2019 - 2025.* Retrieved from Grand View Research: https://www.grandviewresearch.com/industry-analysis/3d-metal-printing-market

Hirtenberger. (2020). *Hirtenberger engineered surfaces*. Retrieved February 2020, from https://hes.hirtenberger.com/en/

IDEA Consult. (2016). *Study on Assessing innovation capability of EU companies in developing Advanced Manufacturing Technologies.* European Commission.

IDEA Consult et al. (2016). *Identifying current and future application areas, existing industrial value chains and missing competences in the EU, in the area of additive manufacturing (3D-printing).* Brussels: European Commission.

IDTechEx. (2019). *3D Printing of Metals 2019-2029.* IDTechEx Research.

Jason Dawes, R. B. (2015). Introduction to the Additive Manufacturing Powder Metallurgy Supply Chain. *Johnson Matthey Technol. Rev.*, 243-256.

Kaspar, J., Häfele, T., Kaldenhoff, C., Griebsch, J., & and Vielhaber, M. (2017). Hybrid Additive Design of FRP Components - Fiber-Reinforced Sandwich Structures Based on Selective Laser Sintering Technology. *Procedia CIRP, 60*, 235-240.

Laboratory of Composite Materials and Adaptive Structures. (2014). Retrieved from www.structures.ethz.ch .

Leutenecker, B., Klahn, C., & M., M. (2015). Indicators and Design Strategies for Direct Part Production. *International Conference on Engineering Design ICED'15.* Milan.

Materialise. (2020). *Materialise Software*. Retrieved from Materialise: https://www.materialise.com/en/software

McCue, T. (2018, June 04). *Wohlers Report 2018: 3D Printer Industry Tops $7 Billion*. Retrieved from Forbes: https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#4b12b5fc2d1a

McCue, T. (2019, March 27). *Significant 3D Printing Foresecat Surges to $35.6 Billion*. Retrieved February 2020, from Forbes: https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#1e9924037d8a

OECD. (2017). *"3D printing and its environmental implications", in The Next Production Revolution: Implications for Governments and Business.* Paris: OECD Publishing.

OECD. (2020). *The Digitalisation of Science, Technology and Innovation: Key Developments and Policies.* Paris: OECD Publishing.

PRODINTEC, et al. (2017). *A STRATEGIC APPROACH TO INCREASING EUROPE'S VALUE PROPOSITION FOR ADDITIVE MANUFACTURING TECHNOLOGIES AND CAPABILITIES: Early statement AM report for EC (D6.3).* Brussels: European Commission.

RINA Consulting et al. (2018). *A STRATEGIC APPROACH TO INCREASING EUROPE'S VALUE PROPOSITION FOR ADDITIVE MANUFACTURING TECHNOLOGIES AND CAPABILITIES: Final AM Roadmap.* European Commission.

Roland Berger. (2018). *Advancements in metal 3D printing Beyond powder bed – Additive manufacturing on the brink of industrialization.* Munich: Roland Berger GmbH.

Sher, D. (2018, November 1). *KTM Technologies presents case for hybrid 3D printed and composite motorcycle parts*. Retrieved from 3D Printing Media Network: https://www.3dprintingmedia.network/ktm-technologies-presents-case-for-hybrid-3d-printed-and-composite-motorcycle-parts/

Stratasys direct manufacturing. (2020). *Manufactured parts on demand*. Retrieved from Stratasys direct manufacturing: https://www.stratasysdirect.com

Türk, D., Einarsson, H., Lecomte, C., & Meboldt, M. (2018). Design and manufacturing of high-performance prostheses with additive manufacturing and fiber-reinforced polymers. *Production Engineering : Research and Development, 12(2)*, 203-213.

Türk, D., Kussmaul, R., Zogg, M., Klahn, C., Spierings, A., Könen, H., . . . Meboldt, M. (2016). Additive manufacturing with composites for integrated aircraft structures. *Procedia CIRP v66*, 306-311. Retrieved from https://www.researchgate.net/publication/303663548_ADDITIVE_MANUFACTURING_WITH_COMPOSITES_FOR_INTEGRATED_AIRCRAFT_STRUCTURES

Türk, D., Rüegg, F., Biedermann, M., & Meboldt, M. (2019). Design and manufacture of hybrid metal composite structures using functional tooling made by additive manufacturing. *Design Science, 5*(E16), doi:10.1017/dsj.2019.16.

TWI et al. (2017). *A STRATEGIC APPROACH TO INCREASING EUROPE'S VALUE PROPOSITION FOR ADDITIVE MANUFACTURING TECHNOLOGIES AND CAPABILITIES: D2.1 Selection of Key AM Sectors for Europe.* European Commission.

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.* European Commission.

Vanguard Initiative 3DP Pilot. (2020). *Pilot action on Interregional innovation projects - Business Plan 'Hybrid 3DP-Carbon Fiber component for Blowers'.* Brussels: European Commission.

White, A. (2018, September 15). *LEGO Brand Group Invests in ·d Printing Firm Evolve*. Retrieved from BricksFanz: http://bricksfanz.com/lego-brand-group-invests-in-3d-printing-firm-evolve/

About the 'Advanced Technologies for Industry' project

The EU's industrial policy approach 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;
- Analysis of industrial value chains and policy needs;
- 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.

More information about the 16 technologies can be found at 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.

September 2021

EA-08-21-248-EN-N

Publications Office
of the European Union