KLASTR ČTPAV MECHATRONIKA

Roadmap: Additive Manufacturing

1st year update

1. Executive Summary

You are holding the updated version of the roadmap for additive manufacturing in the Czech Republic. In the autumn of 2022, we, as the Czech technology platform for additive manufacturing (ČTPAV), developed and published the very first Czech roadmap for this sector. Many partners were involved in its preparation, most importantly the ASTM Centre of Excellence (AM CoE). Many thanks to them for their expert guidance in the development of the roadmap. Both documents have been created in the framework of a project founded by the EU (Operational Programme Enterprise and Innovations for Competitiveness - OPPIK). The basic mission of ČTPAV is to support the introduction of additive technologies and work with them. The main approach of ČTPAV is to communicate current trends and connect research and industry and to support direct transfer of knowledge and technology, linking business and research in the field of additive manufacturing.

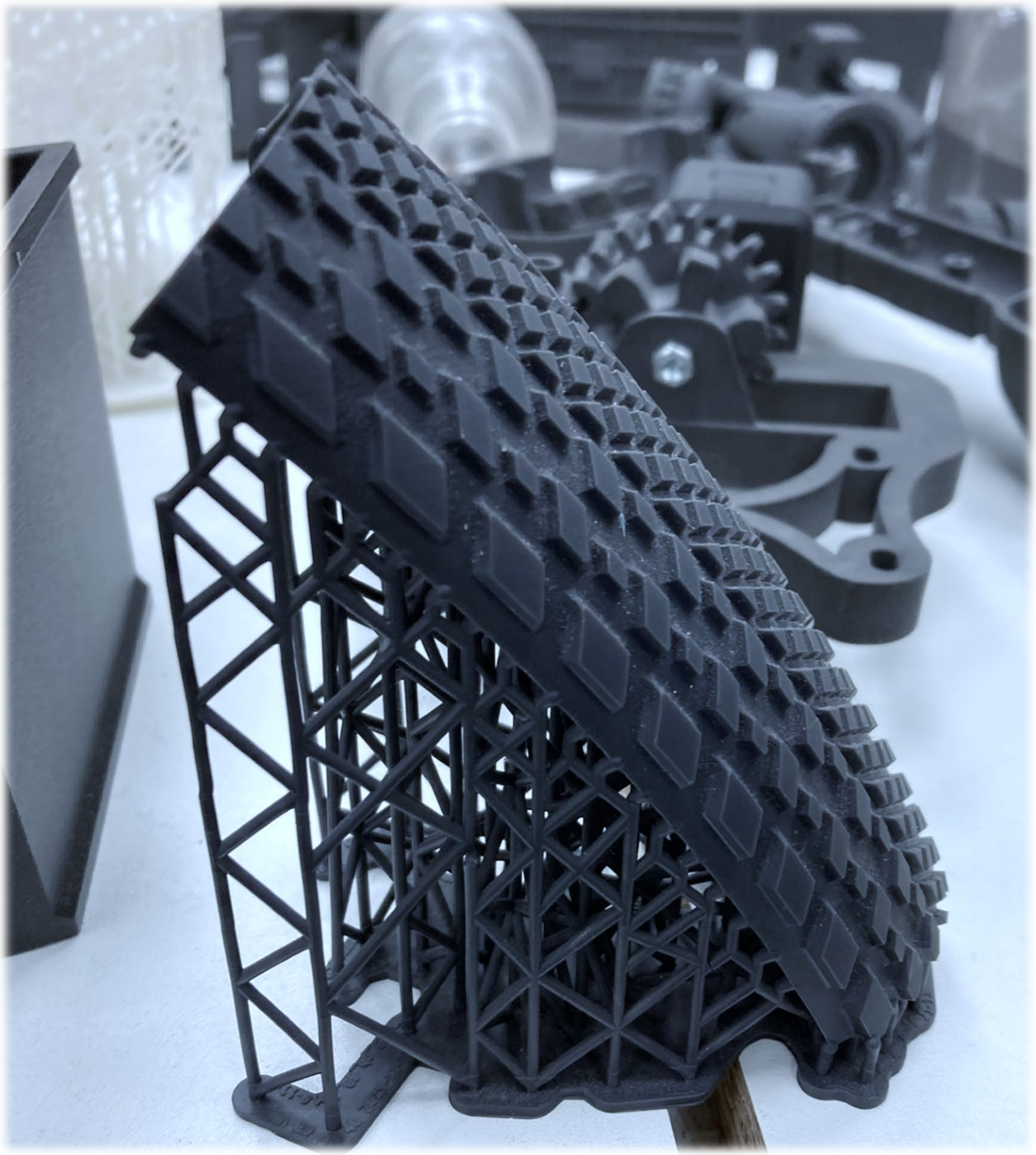
The Roadmap for additive manufacturing describes the current state of additive technologies in the Czech environment and shows the expected direction that these advanced technologies will take. The Czech Republic is undoubtedly an industrial country. Additive technologies are advanced modern technologies that are envisaged for the future. We want our roadmap to show local companies new opportunities for their development and thus help Czech industry to maintain and continue to create high added value.

Most of the work in the first version of the roadmap was devoted to identifying opportunities for further development of additive technologies in the Czech Republic. We then anchored the desired development based on these opportunities in the so-called swim lines. Here we have defined the most important milestones we believe we want to achieve during the first year, i.e. this update, and over the next 10 years. A visualization of the achievement of these swim lines is included in this update.

The first roadmap has opened up many questions and opportunities to reflect on the Czech industrial environment and on high value-added products and services. The work on the updated version has given the CTPAV the opportunity to reflect in detail on some of the traditional Czech industries that have the potential to develop further rapidly and with high quality thanks to additive technologies. In particular, we have incorporated more insights from the aerospace and healthcare sectors. We also focused on which fields have frequent and successful R&D projects in the Czech Republic or how additive technologies are being addressed by local educational institutions. In order to keep the roadmap a simple strategic document that is pleasant and easy to work with, we present here only a summary of our findings.

The main mission of the CTPAV is to disseminate information and motivate the introduction of additive technologies in the Czech industrial environment. If you are interested in more details, please contact us.

We believe that together we can bring the Czech industry and additive manufacturing further.



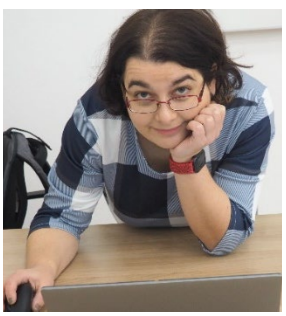
2. About the Authors

Czech Technology Platform in Additive Manufacturing (ČTPAV)

The basic mission of ČTPAV is to support the introduction of additive technologies and work with them. The main approach of ČTPAV is to communicate current trends and connect research and industry and to support direct transfer of knowledge and technology, linking business and research in the field of additive manufacturing.

ČTPAV is part of Cluster MECHATRONIKA (KM), an independent non-profit association whose main goal is to promote additive technologies in the Czech environment. Currently, the environment of additive technologies in the Czech Republic is somewhat fragmented, mostly linked to individual larger companies that act as pioneers of these technologies in the field. The main goal of our activities is to raise awareness of the local society, to present the possibilities that AM brings and that can find application in the Czech industry. Through KM's membership in the National Cluster Association, ČTPAV uses its position in communication with the public administration, e.g. in the creation of subsidy programmes focused on these advanced technologies. ČTPAV is based in Dobřany near Plzeň.

Kateřina Podaná – Cluster manager



Kateřina is originally an economist and linguist, but her marriage and friends led her to technical fields. From the beginning she has worked in the field of international relations and cooperation. First at the University of West Bohemia in the Youth Exchange Centre, where she explained the importance of sharing information and exchanging experiences across borders. Subsequently, she worked as a technology transfer assistant in the research organization COMTES FHT and in 2019 she took over the leadership of projects and development in the MECHATRONIKA Cluster.

As a Cluster manager, she encourages collaboration among business, research, schools and companies. She enjoys accompanying local companies on their development journey. As a board member of National Cluster Association, Kateřina promotes additive technologies among other cluster organizations in the country and spreads AM awareness across the cluster environment in the country.

ASTM Additive Manufacturing Center of Excellence (AM CoE)

Formed in 2018, the Additive Manufacturing Center of Excellence (AM CoE) is a collaborative partnership among ASTM International – and its 30,000 members, Auburn University, EWI, NAMIC, NASA, NIAR, and the MTC representing industry, government, and academia, that conduct strategic R&D to advance standards across all aspects of AM technologies. The center aims to accelerate the development and adoption of additive manufacturing by supporting standardization, developing training, certification programs, providing market intelligence, business strategy, and advisory services via Wohlers Associates, powered by ASTM International.

For further information, please see the AM CoE annual report (AMCoE, 2022), where the accomplishment in the last 12 months include:

- 12 new, fully funded R&D projects that directly fill standardization gaps;
- launch of the Consortium on Materials and Data Standardization (CMDS);
- the new operator certification program;
- the AM CoE's leadership in three America Makes projects with a combined total effort of more than $1 million;

ASTM International

Committed to serving global societal needs, ASTM International positively impacts public health and safety, consumer confidence, and overall quality of life. We integrate consensus standards – developed with our international membership of volunteer technical experts – and innovative services to improve lives. Helping our world work better.

Dr Martin White, ASTM Head of Additive Manufacturing Programs - Europe

Martin is a Materials & Structures Specialist, with 20 years of experience in both academic and industrial fields. His recent career has focused on the Certification & Production of Aerospace structures, ranging from the A350-900 XWB Main Landing Gear at Safran Landing Systems, to his most recent role as Chief Engineer for Additive Manufacturing at GKN Aerospace. He spent his early career studying with Rolls Royce at Swansea University to obtain a Doctorate in High Temperature Materials for Gas Turbine applications, as well as a Masters in High Strength Steels for Landing Gears. At Frazer-Nash, he worked across multiple industries – including Aerospace, Civil Nuclear, Defense, and Oil & Gas.

Martin has previously developed a fit-for-AM-purpose Quality Management System for Additive Manufacturing applications in Aerospace (as Chief Engineer) and achieved AS9100 & ISO9001 in under a year.

Dr Alberto Bordin, ASTM Technical Lead – Europe

Alberto is an AM Engineer, with 10 years of experience maturated during his PhD studies and industrial experiences. In his early career, he obtained a Doctorate in Manufacturing Engineering from Padova University where he studied the post-process behavior of Additively Manufactured Titanium alloys. He later entered the Motorsport environment where he specialized on development and industrialization of products manufactured by metallic AM technologies. He contributed to the development of engine and suspension devices during his time with the Scuderia Ferrari, before moving to Pankl Racing Systems where he played a key role to develop the first Halo Screen safety device. In his latest industrial experience at 3T- AM, Alberto led an team to develop Aerospace and Medical applications for prototyping and serial production.

Alberto contributed to implement and achieve the Aerospace Quality Accreditation AS9100 for a new AM facility in 2019, and he then achieved the qualification for Approved Internal Auditor for AS9100 Standard in 2020.

COMTES FHT a.s.

COMTES FHT is a leading private research organization in Czech Republic which provides research and development services in the field of metallic materials and introduces new forming and heat treatment processes, mainly in key sectors comprising the engineering, automotive and power industries.

In recent years, COMTES FHT researchers have also been working on additive technologies, process and material characterization, exploring practical applications testing materials for bioimplants and more. COMTES FHT runs a Science and Technology Park in Dobřany (near to Westbohemian metropole Pilsen) which is equipped with various deposition system for Additive Manufacturing. Since 2016 COMTES FHT a.s. is an active member of Klastr MECHATRONIKA and was also one of the founding members of ČTPAV.

Ing. Martina Koukolíková, Ph.D.

Martina studied materials engineering at the University of West Bohemia in Pilsen. Since 2007 she has been working in COMTES FHT on research and characterization of metallic materials. She focuses on research and development of progressive steels and superalloys for power and chemical industry, additive manufacturing and determination of causes of operational and manufacturing failures of components. She regularly presents the results of her research at prestigious conferences and events for the professional public.

Since 2018 she has been intensively involved in the characterization of materials prepared by metallic AM technologies, using mainly light and electron microscopy, EBSD and other methods. Martina has experience in national and European research programs. She is also behind the successful international project 3D COVER.

Prof. Ing. Ján Džugan, Ph.D.

Prof. Džugan obtained his Ph.D. in the field of Materials at West Bohemian University in Pilsen, Czech Republic. He was employed at SKODA Research institute in Pilsen where he was dealing mechanical testing. He worked as post-doc 4 years at nuclear research institute Helmholtz Dresden-Rossendorf, Germany and over one year at Fracture Research Institute of Tohoku University in Japan. From 2006 he joined COMTES FHT in Pilsen, Czech Republic, where he established mechanical testing laboratory and later become R&D Director.

Prof. Dzugan is author or co-author of over 200 scientific papers. He has been involved in over 30 publicly funded projects. He is lecturing at West Bohemian University in Pilsen. He is supervisor or Bc., MSc. and Ph.D. students. His main scientific interest are mechanical testing and additive manufacturing. He is member of many international technical organizations. He is also member of ASTM, where he is leader of E28.04.01 Task group on small specimens group and also in chairman of the ISO/ASTMF42-JG61 on Orientation and Location Dependence Mechanical Properties for Metal Additive Manufacturing.

3. Introduction and Problem Statement

Additive manufacturing is a technology of the future that spans many industries - medical, tooling, aerospace, automotive or construction. The Czech Republic is a traditional industrial country and needs to keep up with current trends and developments. There is no time to be afraid of being a pioneer in progressive technologies and fields.

The AM-Roadmap address identified technology and market barriers that impede the rapid commercialization, competitiveness and productivity of the whole additive manufacturing supply chain. It shall help industry to exploit the competitive advantage to be gained by using additive manufacturing for prototypes, tooling and end-use parts. *(UK, A. M. (2018). National Strategy 2018-2025)*

Czech companies are aware of the importance of this sector. In this 1st edition of the AM-roadmap, ČTPAV outlines the direction of development. We have connected foreign and Czech stakeholders and developed this roadmap as part of an EU-supported project. It is a strategic but in the first year also a living document, which is not meant to end up in a drawer but to provide inspiration and knowledge to the reader.

We believe that the very creation of this roadmap will add to the importance of Czech companies and Czech industry. Only a few countries worldwide are strategically involved in additive manufacturing in this way (*see figure 1*) additive manufacturing is usually included in a wide range of broader roadmaps such as I4.0, Smart Manufacturing etc.

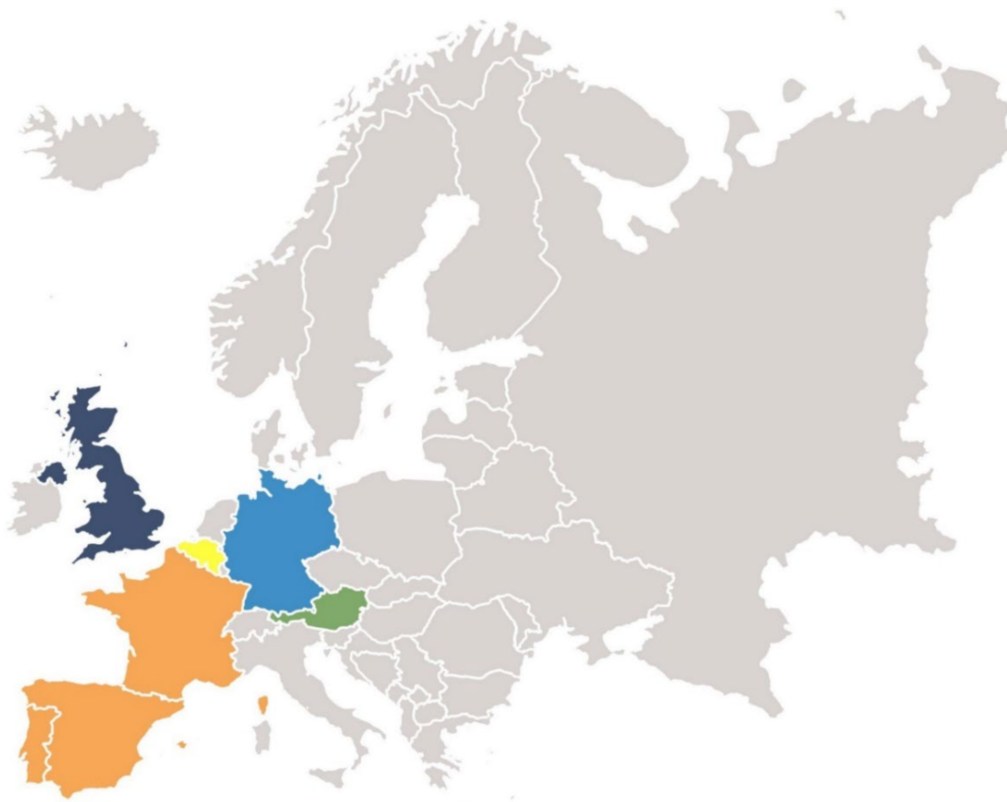


Figure 1: highlighted countries with AM-Roadmap

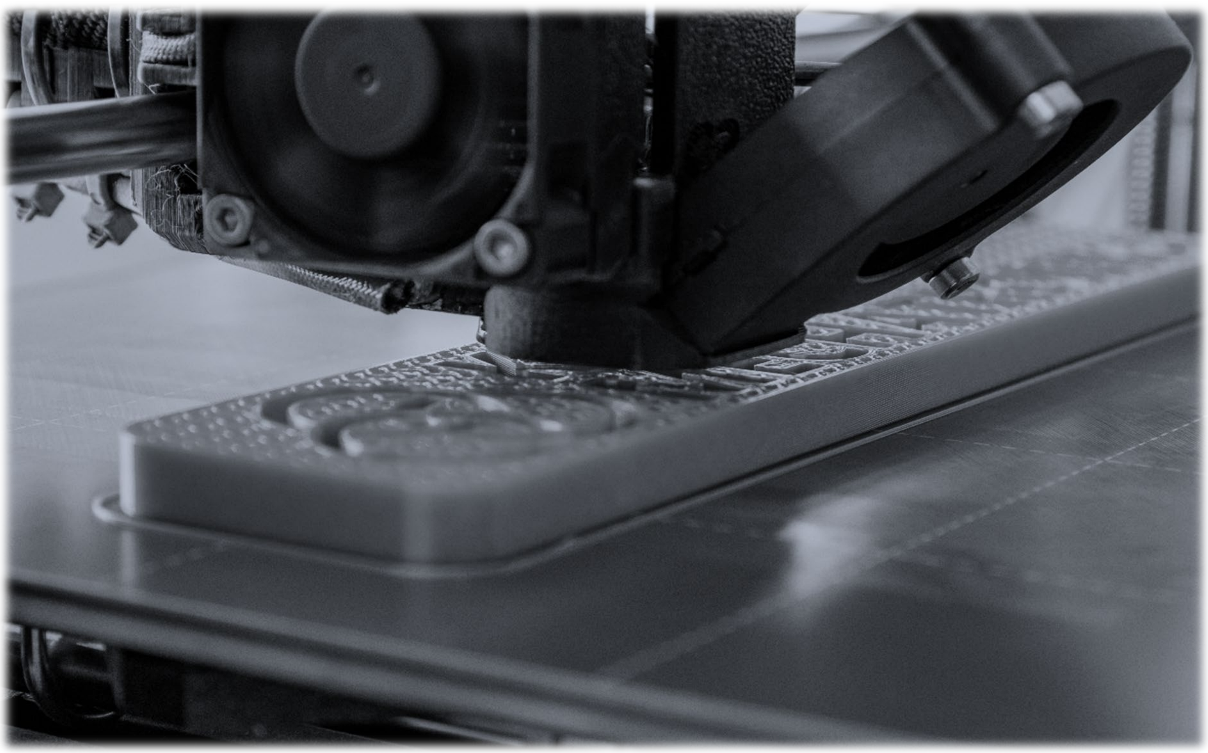
We also analysed the existing and available roadmaps in terms of pragmatism. We are not after lofty goals, we want this document to be understandable and practical. AM roadmaps often include a big portion of generalized state-of-the-art but only few cases suggest pragmatic solutions to enhance AM maturation and adoption (*see Figure 2*)

	Materials	Processes & Design	Post Processes	Software & Data	Quality & Standards	Skills & EWD	Comprehensive	Level of Pragmatism
UK	X	X		X	X	X	2	1
USA	X	X	X	X	X	X	3	2
Bavaria	X	X	X	X	X		2	1
South Africa	X	X	X	X		X	2	3

Ranking:

1 LOW 2 MID 3 HIGH

Figure 2: A. Bordin, COMAT 2022



4. What is Additive Manufacturing?

Additive Manufacturing is defined in (52900:2021) as the ‘process of joining materials to make parts from 3D model data, usually layer upon layer as opposed to subtractive manufacturing and formative manufacturing methodologies’.

The categories of the technology can be seen in Figure 3.

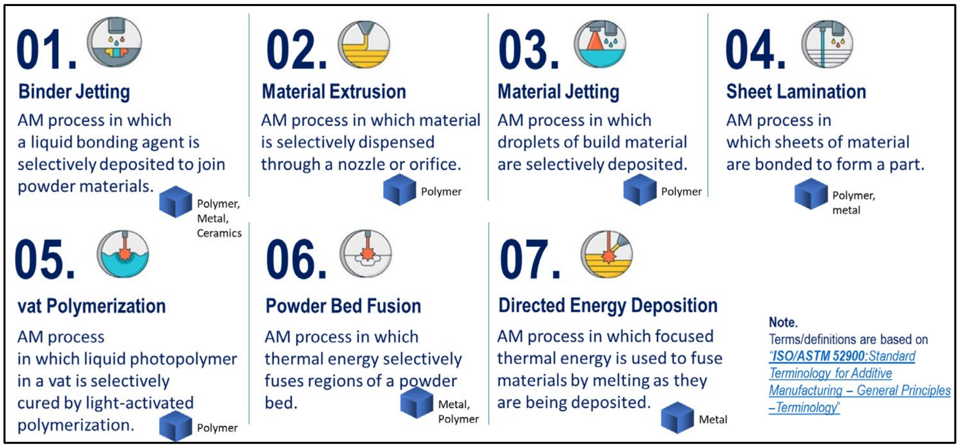


Figure 3 - Additive Manufacturing Technologies as defined in ISO/ASTM 52900

Global Additive Manufacturing Overview

Additive Manufacturing has been making significant gains across the global market in recent years, with an increasing portfolio of products and services now available. Evidence of this growth can be seen in detail in the latest release of the Wohlers Report (*Wohlers Report, 2022*), along with information on various industry sectors, regional comparisons, and the development of various Additive Manufacturing technologies.

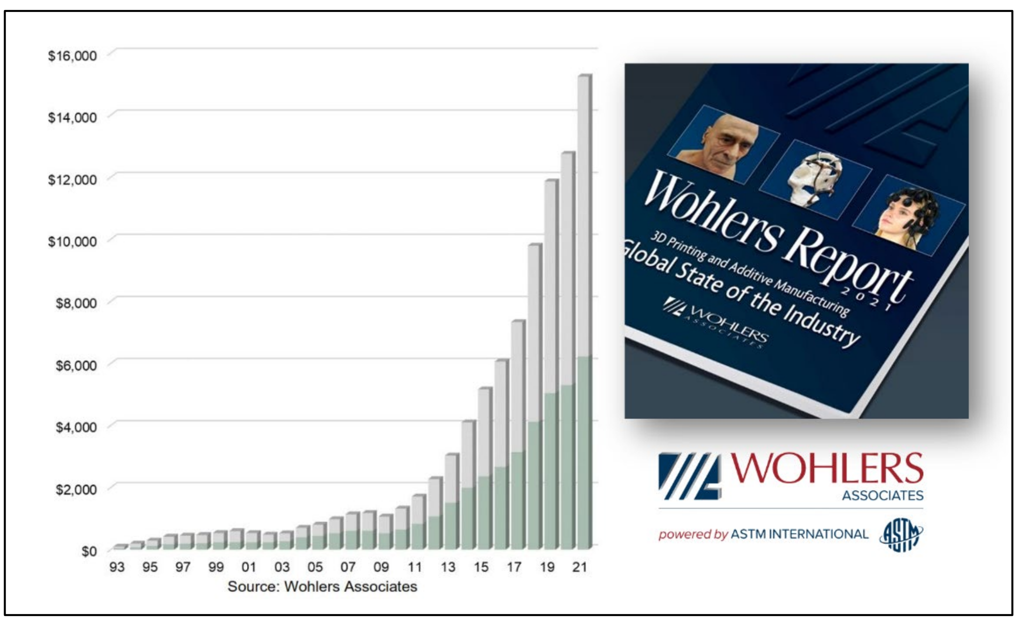


Figure 4 - Growth of the Additive Manufacturing Industry, Wohlers Report 2022

Consistent industry expansion over the last ten years is highlighted in Figure 4 *(Wohlers Report, 2022)*. Last year the industry grew by 19.5% compared to 7.5% before that. In terms of the value of the industry, it is estimated at $15.244 billion, 0.1% of the world manufacturing economy. This roadmap document directs the reader to review existing literature for further details.

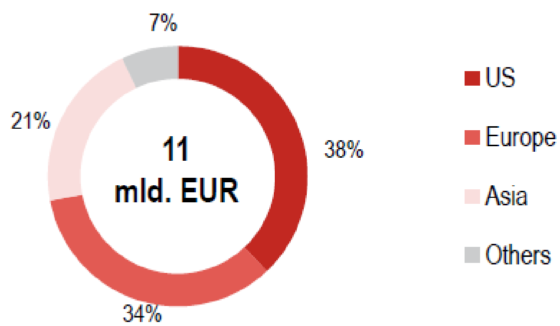


Figure 5: Geographical distribution of the additive manufacturing / 3D printing market (3D Wiser)

Additive Manufacturing Technology Status

With the increase in the industry size highlighted in the previous chapter, the adoption of Additive Manufacturing is evolving. The initial adoption of the Aerospace and Medical industry has helped to advance the technology, and as the supply chain widens and the use increases, therefore the costs also begin to lower. A top-level overview of the technology status can be seen in Figure 6 (Seifi), noting that the path to Standardization will help to facilitate even wider adoption, and lowering the entry to the technology.

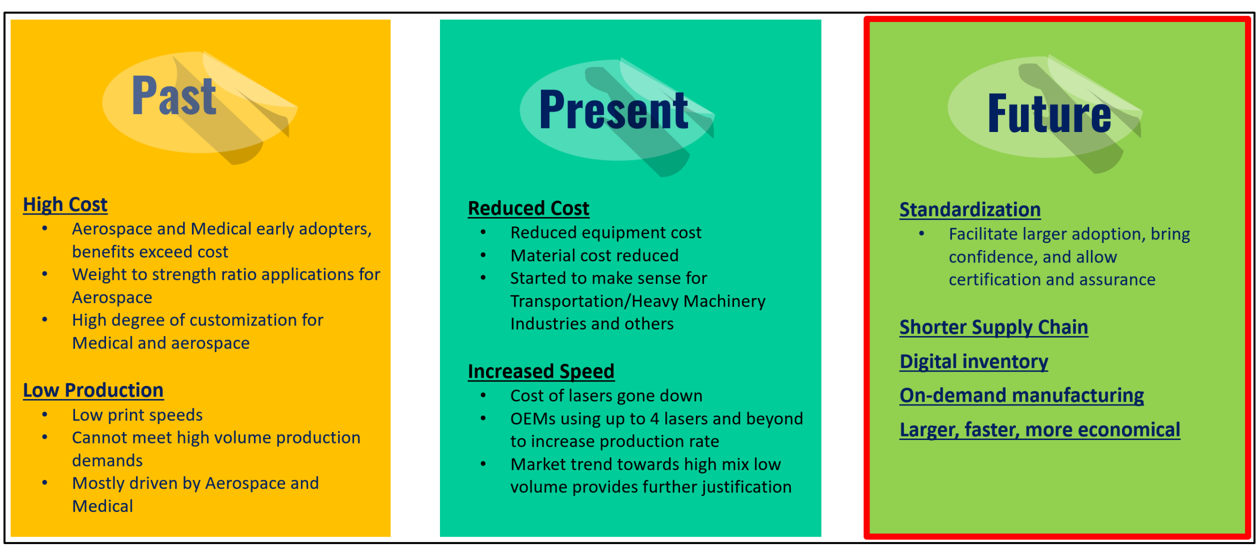


Figure 6 - Overview of adoption of AM Technologies, M. Seifi, ASTM International

From an industry perspective although Aerospace has been an early adopter, the certification and qualification requirements have limited some of the applications until the technology has more demonstratable experience of use in critical applications. The industry landscape comparison in Figure 7 *(Berger, 2013)* is still widely correct today, with tooling applications providing higher rates along with medical applications.

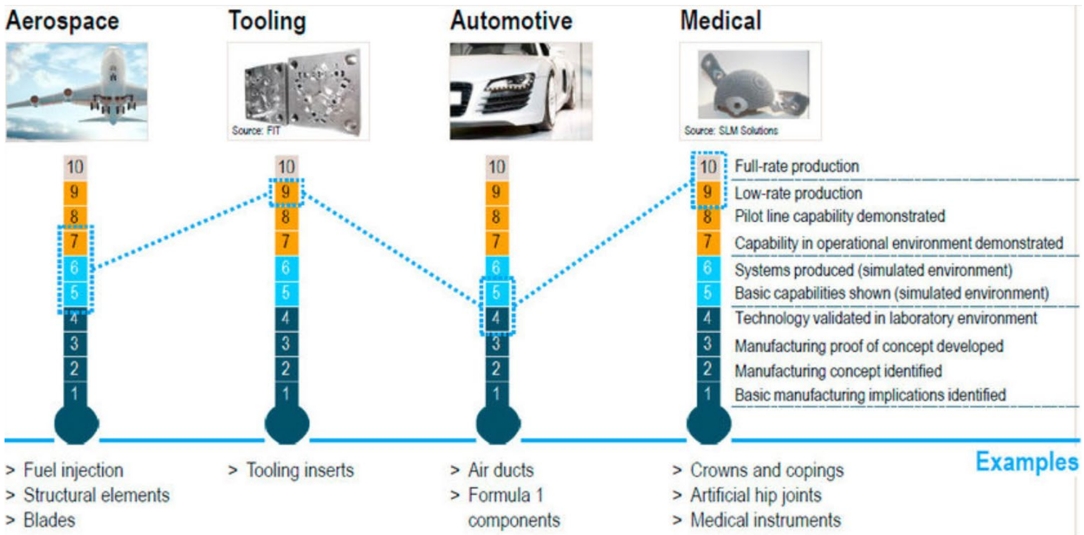


Figure 7 - Approximate assessment of Technology Readiness Levels as reported by Roland Berger

Additive Manufacturing provides some significant advantages, including increased design complexity, novel geometries than cannot be created by 'traditional' manufacturing methods, and the potential for reducing cost and increasing sustainability. To fully unlock this potential, there are several technology 'pathfinder' milestones that need to be achieved. Figure 8 (*Gorelik, 2020*) shows the evolution of these pathfinder blocks, and it is noted that the change from 2017 to 2020 has been slow but steady. Some of the key longer term aims include the development of public specifications and Standards, as well as the increased maturity of AM equipment.

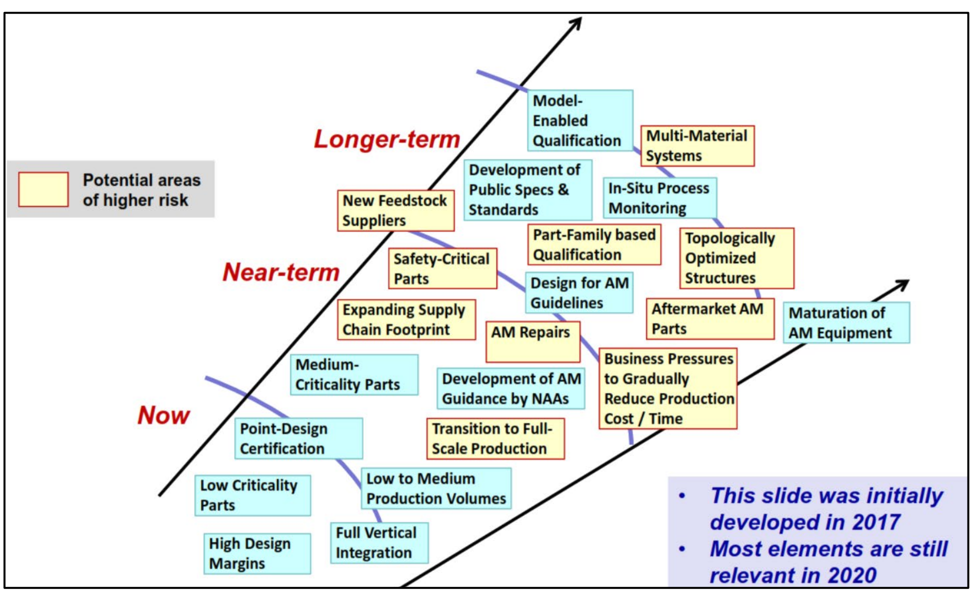


Figure 8 - Expected Evolution of the AM Landscape, M. Gorelik, FAA

Current Challenges

There are several challenges or perceived barriers to widespread adoption of Additive Manufacturing, both technical and commercial. A top-level overview can be seen in Figure 9 (Seifi). The UK Additive Manufacturing roadmap (*UK, 2018*) breaks these challenges down into key topic areas as per Figure 7, which provides a good overview of some of the current blockers. Note that although this document was written in 2018, the barriers are still present today.

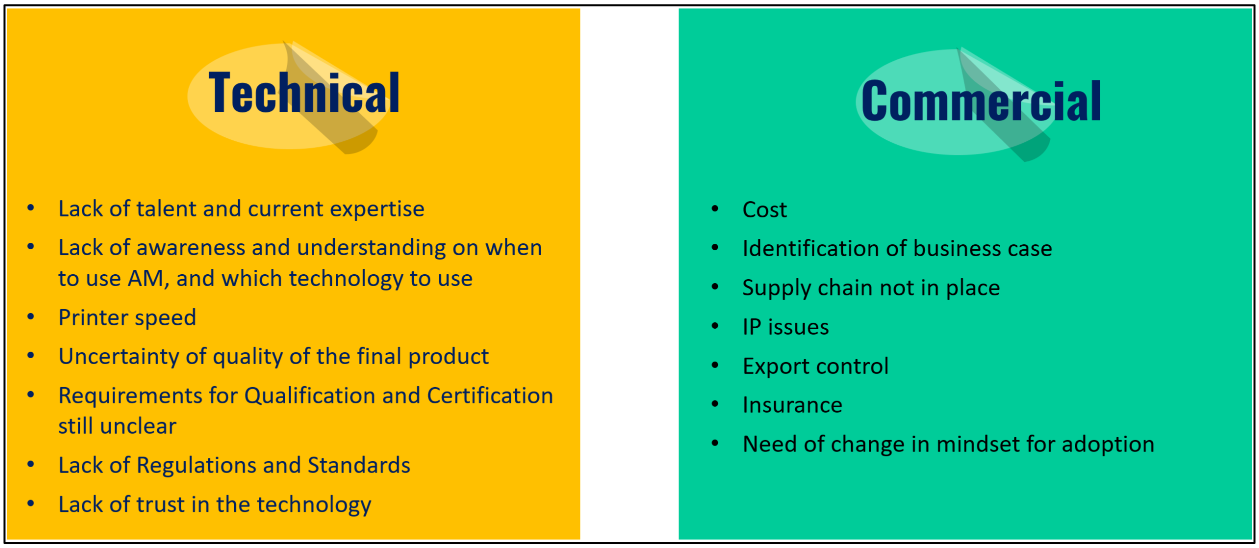


Figure 9 - Top level challenges for Additive Manufacturing, M. Seifi, ASTM International

Thematic working group	Summary of commonly perceived barriers
Cost/ Investment/ Financing	Funding to increase awareness and reduce risk of adoption (testing, scale-up, machine purchase) – especially for SMEs, understanding of full costs (including post-processing, testing) and cost of materials
Design	Need for guides and education programmes on design for additive manufacturing. Better understanding of design for its recognised constraints, availability of suitably skilled designers, security of design data
IP, Protection and Security	Current IP and security methodologies and legal systems are not appropriate for the digital networks and ways of working required for additive manufacturing. Global IP leakage and cyber security concerns reference manufacturing systems preventing rapid technology adoption
Materials and Processes	Understanding properties in different processes / machines / applications, size, throughput, QA, costs, availability (IP constraints, independent suppliers), use of mixed materials, recyclability, biocompatibility
Skills/ Education	Lack of appropriate skills (design, production, materials, testing) preventing adoption, up-skilling current workforce vs. training of next generation, education of consumers, awareness in schools
Standards and Certification	Perceived or actual lack of standards – all sectors / sector specific (especially aero / health / motorsport), for processes / materials / software / products / applications
Test and Validation	Need data libraries, standards for tests (general and sector specific), materials/ in-process / final part, tests for higher volumes, non-destructive testing, QA through lock-in c.f. open access to data

Figure 10 - Challenges highlighted from the UK Additive Manufacturing Roadmap

5. Megatrends

What is a Megatrend in the context of Manufacturing?

The term 'Megatrend' with relation to manufacturing technologies can be classed as 'powerful, transformative forces that change the global economy, business, and society. Megatrends both drive and are driven by disruptive innovations' (*Lydon*). In this context, there are multiple related technologies that Additive Manufacturing is associated with as part of a wider megatrend in manufacturing technology (and beyond). Industry 4.0 is the term defined by the World Economic Forum that drives this revolution. Global events such as the COVID19 pandemic has driven industry to be more adaptable with developing technologies.

The evolution towards digital manufacturing leads to the linking of multiple technologies, enabling engineers to leverage digital domains alongside physical systems. An example of how such an infrastructure works can be seen in Figure 11 (*Seifi*).

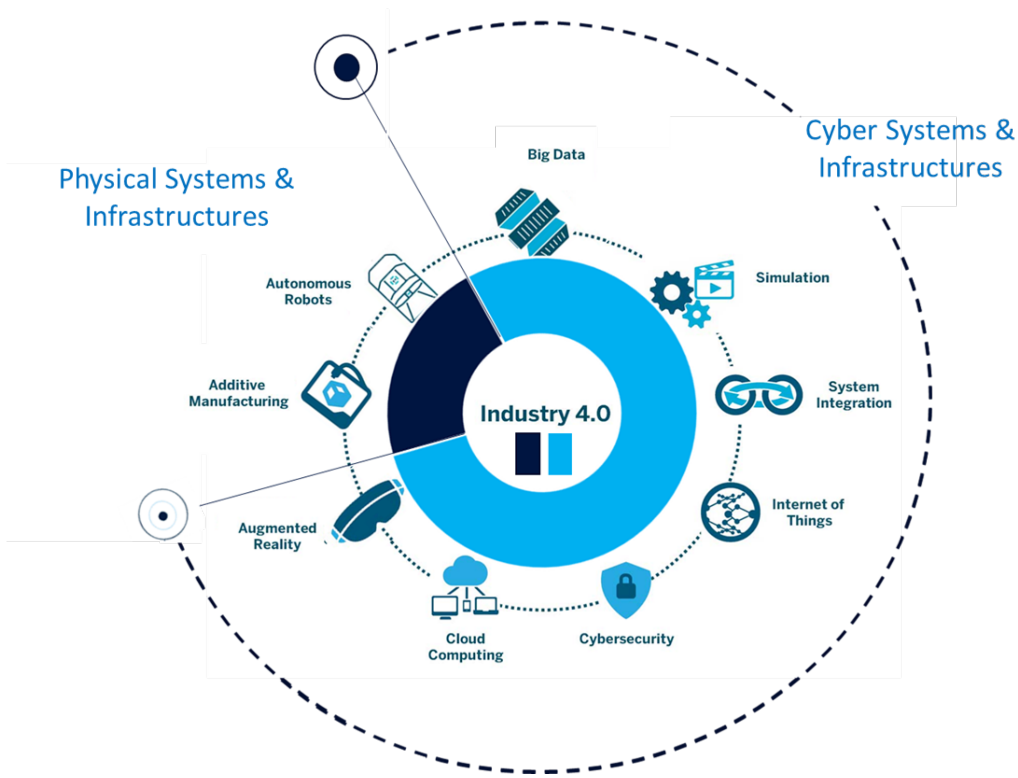


Figure 11 - The trend on the convergence of emerging technologies in the Industry 4.0 era, M, Seifi, ASTM International

Recent trends in technology are shifting from *technology focused* to *application focused*. This has been demonstrated with the urgent drive towards zero-carbon emission applications – for example, UK Aerospace Technology Institute 'Fly Zero' challenge (https://www.ati.org.uk/flyzero/), and the EU Mission: Climate-Neutral and Smart Cities project (https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en). In these type of projects, Additive Manufacturing can provide a significant supporting role.

Key Trends in Additive Manufacturing

As described in previous sections, Additive Manufacturing is progressing globally across several technology areas. Examples of top-level trends include:

Hardware

- Industrial vs 'Hobbyist' – Industrial use is classed as 'professional' engineering organizations with a controlled facility, vs the 'hobbyist' home, school, or maker space printing setup. The cost of home printers has been become competitive, with the likes of Prusa Research in the Czech Republic being a well known provider of these machines, moving towards the professional market (https://www.prusa3d.com/).
- Modalities – effectively different types of Additive Manufacturing, see ISO/ASTM 52900 (52900:2021, 2021) for definitions and details
- In Process Monitoring – This is the ability to monitor the Additive Manufacturing process during the layer-by-layer deposition manufacturing. This capability is a key R&D area currently, particularly for quality assurance of products.

Software

- Automation – As Additive Manufacturing moves towards higher volume of components and manufacturing methods, automation will become a crucial step to drive reductions in cost.
- Design Assist – There are now multiple software packages that can assist design in Additive Manufacturing, ranging from 'Generative Design' software to optimization solvers for automated metallic support structure design.
- Linking the Value Chain – Combining processes and being able to leverage a 'digital thread' is significant research area currently, especially when combined with hardware technologies such as in process monitoring.

Standards development is a strong indicator of industry needs. The ASTM International Center of Excellence (https://amcoe.org/) has run a funded Request for Ideas research program to accelerate standards for Additive Manufacturing since 2018. Figure 12 (*Seifi*) shows the increase in developing or optimizing test methods over recent years, and in the last two years the demand for standards data and inspection/qualification topics has rapidly grown. The recent formation of the ASTM Subcommittee F42.08 for Data (https://www.astm.org/get-involved/technical-committees/committee-f42/subcommittee-f42) has likely provided the surge in data related topics, and the increase in inspection and qualification ideas is a good indicator of increasing maturity in the technology.

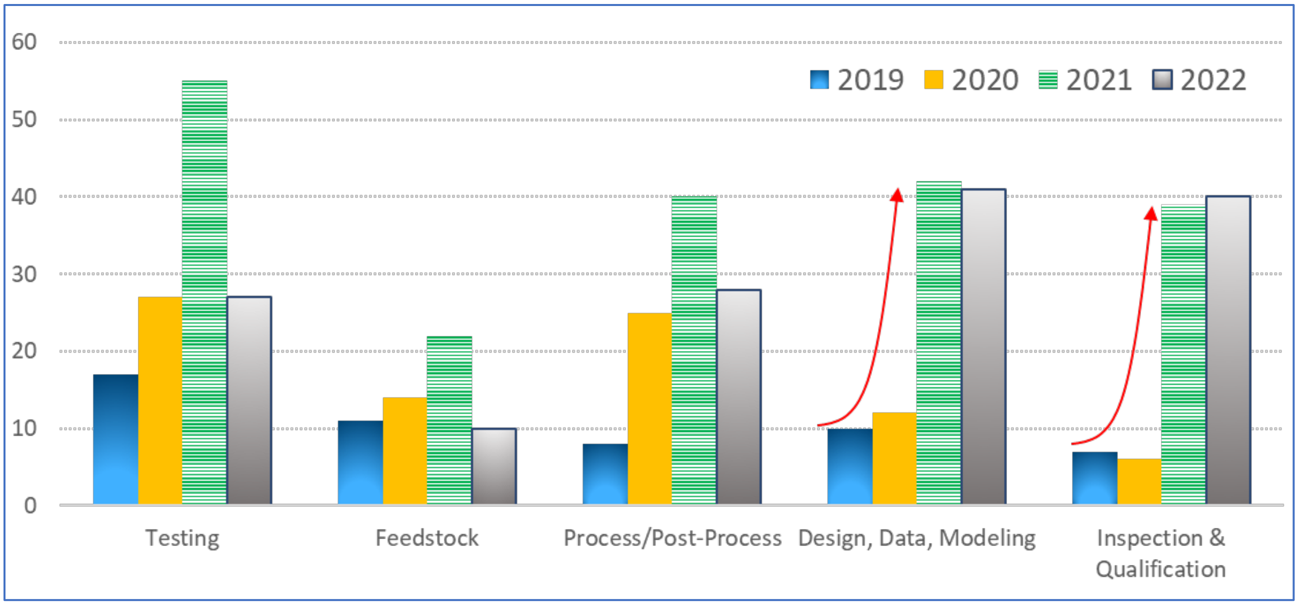


Figure 12 - Trends in demand for Additive Manufacturing Standards, M. Seifi, ASTM International

Europe Region

Europe has one of the largest market shares for Additive Manufacturing, as seen in Figure 13, (*EY, 2019*), with Germany being home to 24% of 3D companies in 2019 – second only to the USA (*AMFG Autonomous Manufacturing, 2019*). Recent research from CECIMO highlights that the investment in the European region will continue, as shown in Figure 14 (*CECIMO, 2021*). Furthermore, CECIMO expects Aerospace and Automotive growth, driven by the transition to electric vehicles and net zero aviation. This reflects the global trends highlighted in Section 4.1. The indication is that metallics and plastics have the strongest order intentions, potentially leading to an increase in demand for Additive Manufacturing machines and services. Evidence of this can be seen in Figure 15 and Figure 16, with information from (*CECIMO, 2021*).

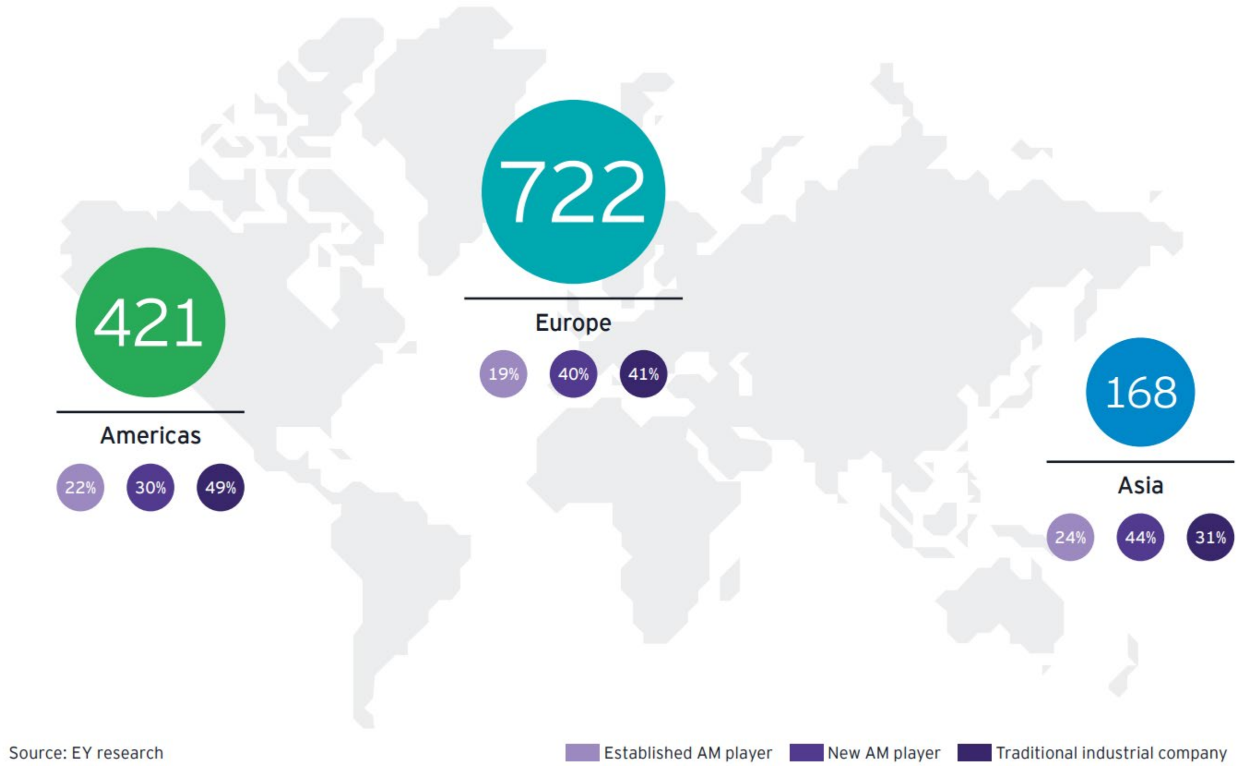


Figure 1 - Overview of Global AM Players, Global EY Report

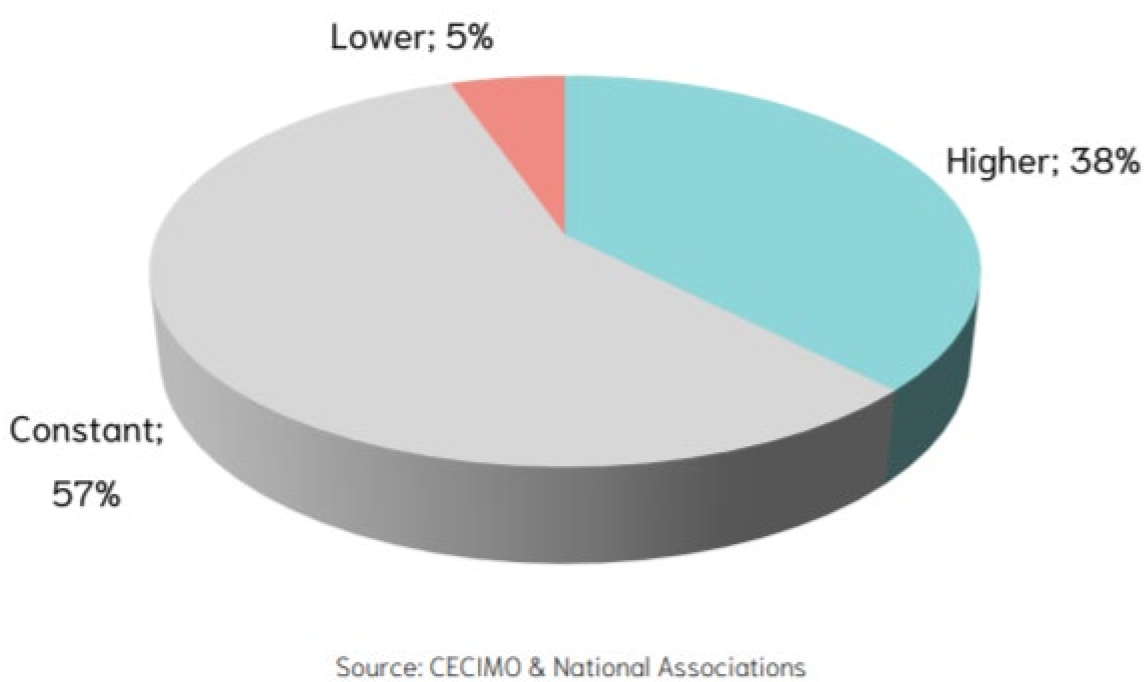


Figure 2 - Investment Indications from Autumn 2021, CECIMO

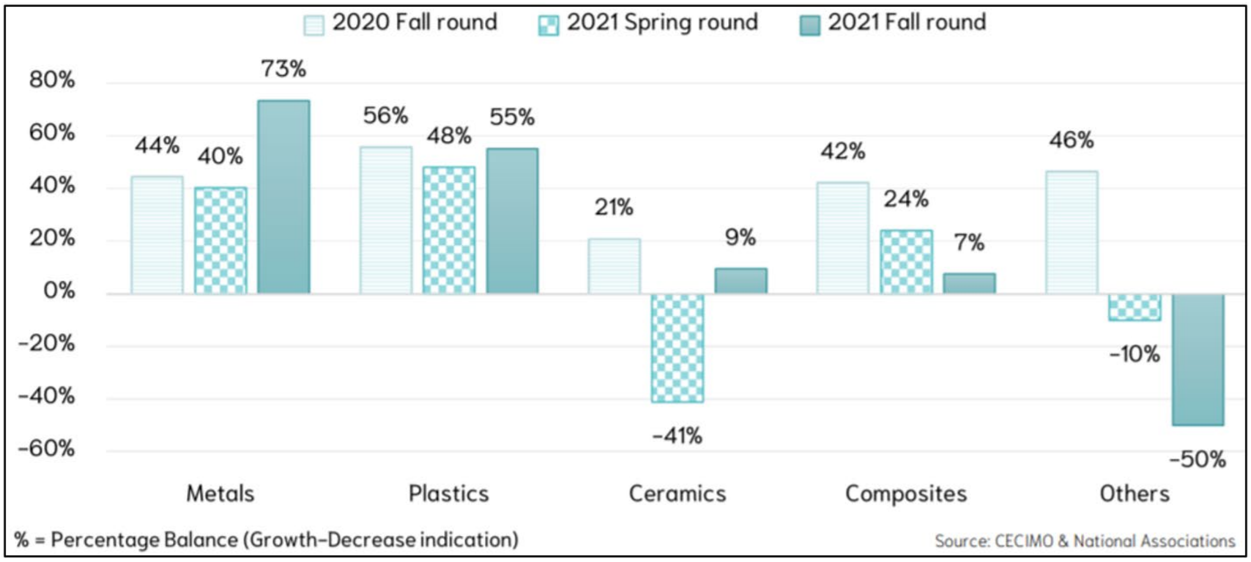


Figure 3 - AM Material Trend Indication, CECIMO

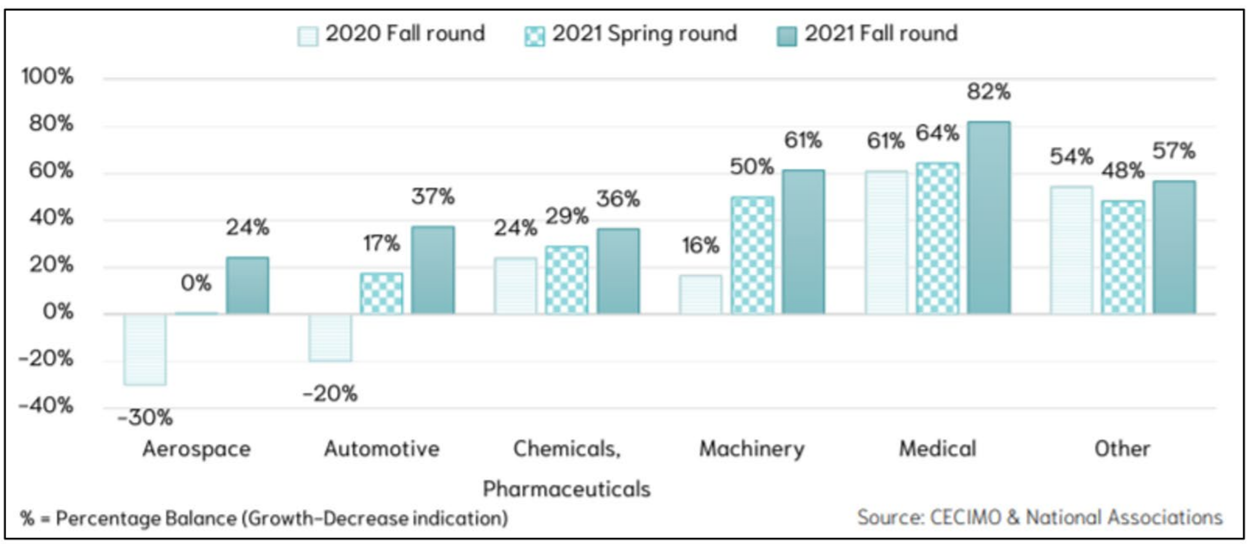


Figure 46 - Business Trend Indications, CECIMO

A number of European countries have created a national strategy for Additive Manufacturing: United Kingdom (*UK, 2018*), Germany (*Bayern Innovativ , 2019*), and Austria (*Bundesministerium, 2018*) (amongst others) which outlines their manufacturing strategies and target sectors. This roadmap for the Czech Republic will provide a local overview and provide the basis for comparison against other regions.

Czech Republic and Local Region

Europe is leading the development and commercialization of AM machines (in particular for metal applications) followed by U.S. and China when considering leading market intelligence publications (*Wohlers Report, 2022*). In Central Europe, Germany is consistently leading the innovation and maturation of AM technologies in all areas, whereas other neighboring countries seem to drive innovation for specific technological strands.

The current status of Additive Manufacturing in the Czech Republic is not currently reported in the Wohlers report; however, neighboring countries of similar sizes and economies are considered. In this section, a brief overview of the latest evolutions in the field of AM is provided for those countries.

Austria (Wohlers Report, 2022): The Austrian AM community kept on growing in the last few years despite the COVID pandemic, particularly in the field of innovative technologies. A significant group of startups and young organizations are growing, supported by public funding and venture capital. Cubicure is developing high-performance polymers by hot lithography (VPP), Incus 3D is innovating metal AM processes by developing lithography-based metal manufacturing (LMM). In the field of Ceramics, the established Viennese-based Lithoz is expanding its offer by releasing more efficient AM machines and process capabilities. In other areas of the AM ecosystem, EOS invested in the powder manufacturer Metalpine, the second metal AM feedstock producer in the country after the Voestalpine Group. Austrian community is active in organizing AM forums and international conferences on AM.

Hungary (Wohlers Report, 2022): In Hungary, the pandemic had minimal impact on the AM industry, which contributed to the significant market growth in 2021. The Medical field is arguably the most promising field of application for AM technologies, bringing an increasing demand for VPP and metal AM technologies. Hungarian AM companies have been quite active in the field of Material Extrusion (MEX) AM modalities, seeing companies expanding their offer on machines and dedicated software such as Craftbot. A vibrant group of startups is entering the AM market to develop AM machines, and software and establish service providers to satisfy the increasing demand for metal applications. The Hungarian government and EU supported small Hungarian companies to help them invest in AM-related topics, in particular: advanced applications, automation, methods for DFAM, and AM machine improvements to increase the speed and precision of metal and polymer machines.

Poland (Wohlers Report, 2022): The main highlight in this country is the launch of the government-funded educational program called Laboratories of the Future (budget over 200 million USD). Students will acquire practical skills through experimentation, within laboratories equipped with 3D printing and other capabilities. Main innovations are brought in the field of material extrusion AM technologies (MEX), where companies like SkribiArt and Grupa Azoty are developing AM machines and feedstocks. The country has hosted the 3D Solutions international fair in 2021 and other minor national events are held every year to promote AM related activities.

Czech Republic is not mentioned by the Wohlers Report 2022, however 2021 a professional survey among Czech, Hungarian, Slovak and Romanian companies conducted by a private company 3D Wiser was released. The survey was focused on the perception, current and future state of the professional and industrial 3Dprinting market. In Europe, 17% of companies with more than 250 employees and 5% of companies with more than 10 employees currently use professional or industrial 3D printing. The usage of 3D printing in companies with more than 10 employees is 6% in the Czech Republic, 4% in Slovakia, 3% in Hungary and 2% in Romania. Businesses in Europe most often use 3D printing for prototypes or models for internal use in the production process. (*see Professional 3D Printing in Central Europe, 3DWiser, 2021*)

6. Czech Republic Additive Manufacturing Roadmap

Introduction & Approach

As part of the collaboration between Klastr MECHATRONIKA, COMTES FHT and ASTM International Center of Excellence, a series of stakeholder engagement exercises were designed to engage with Czech Republic industry and academic representatives. The process for the roadmap development is outlined in Figure 17, showing the need to gather input from the community before defining the challenges and engaging the roadmap.

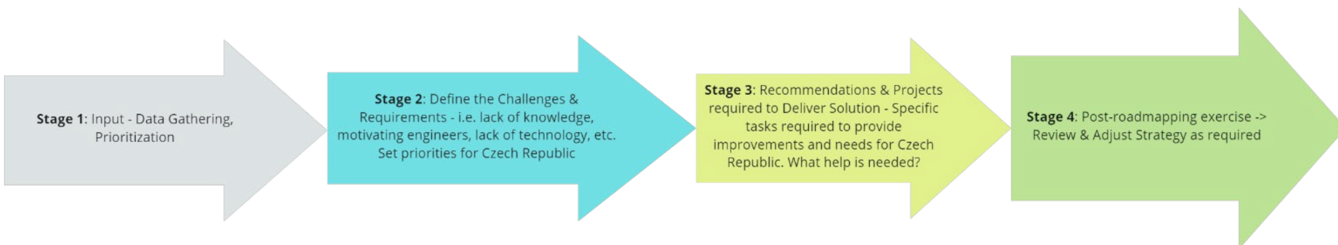


Figure 57 - Process for developing Czech Roadmap

Virtual Workshop & Engagement

This initial workshop and discussion provided Czech stakeholders with an overview of the current state of the art with regards to Additive Manufacturing, including an overview of the Standards landscape, routes to industrialization, and considerations for building a business case.

Following the technical presentations from ASTM International, a virtual discovery workshop provided the initial output highlighted in Figure 18. There were a few strands identified, which became the basis for the following in person workshops.

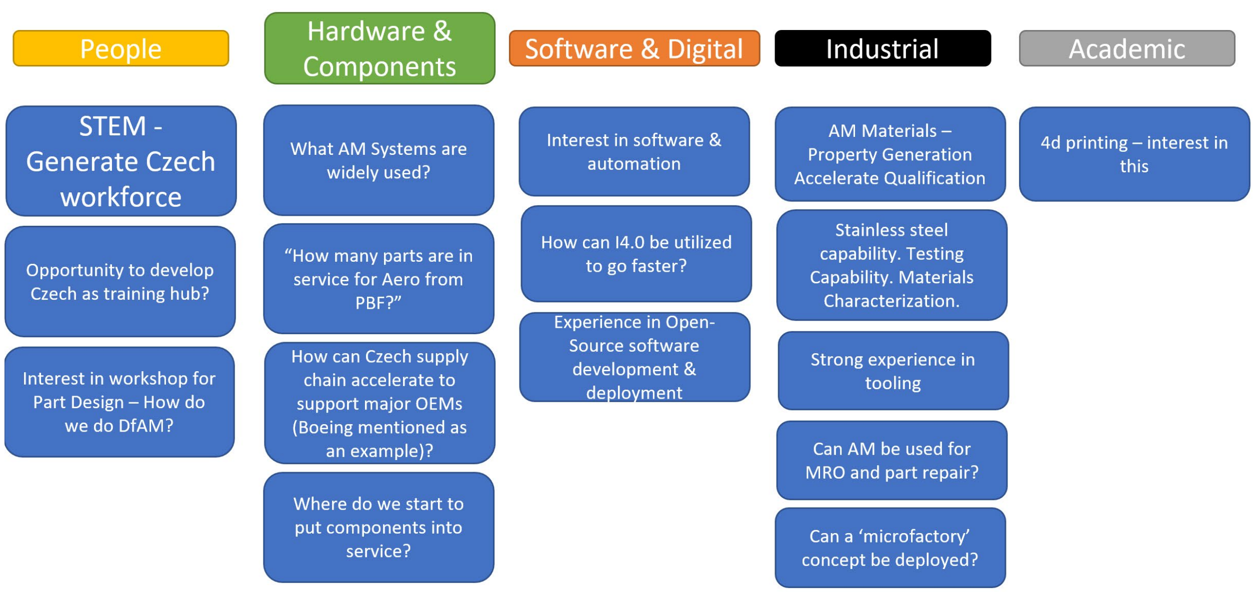


Figure 6 - Top level topics raised at initial Virtual Workshop

In Person Roadmapping & Stakeholder Engagement

Based on the output from the virtual engagement and additional focused discussions, four key strands were identified:

- **Technology**: What types of Additive Manufacturing technologies are of interest?
- **Applications**: How will the technology be applied?
- **Infrastructure**: Consider how the manufacturing infrastructure is set up for additive in the region.
- **People**: What is the position and the needs of the Workforce in the region?

Two working groups were created during the workshop, one representing industrial interests and the other focusing more on academic needs and inputs. Starter questions for each topic review can be seen in Figure 19. Following the focused group sessions, wider open discussions were led by ASTM International (Figure 20), allowing the comparison of the two groups.

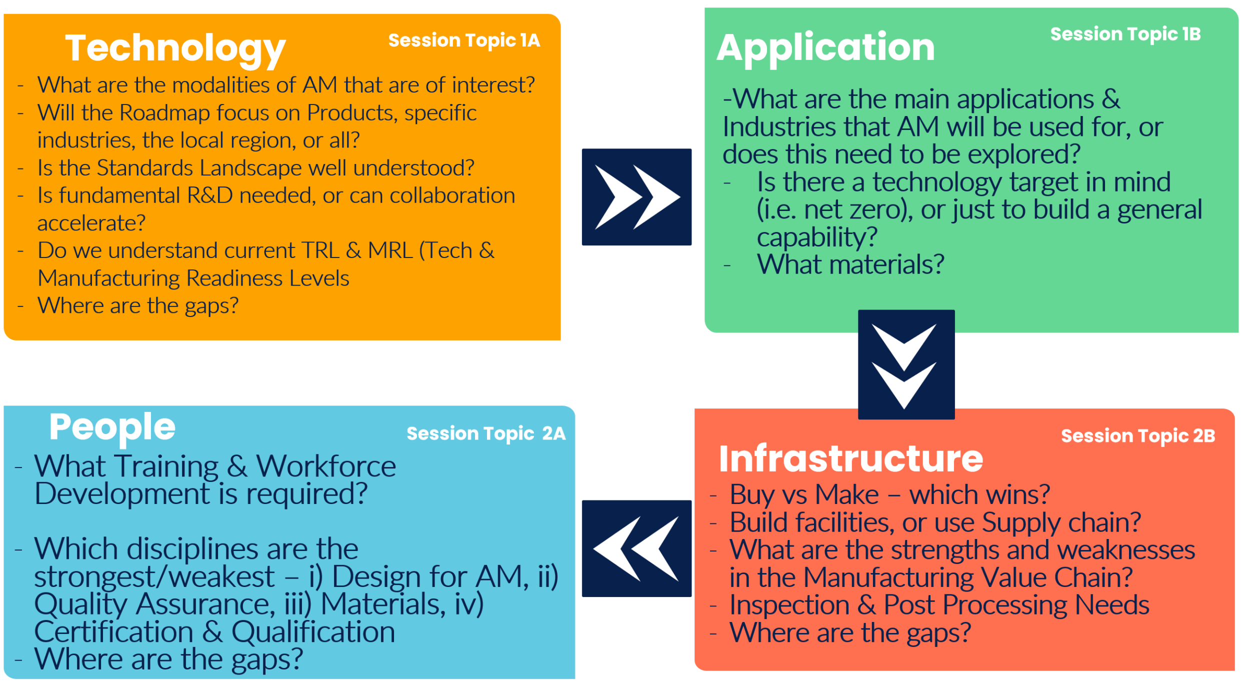


Figure 7 - In person Workshop Topics & questions

Figure 20 - Workshop activities at ČTPAV, led by Dr Alberto Bordin, ASTM International

Supporting Organizations

For the creation of the roadmap, both perspectives on the issue were important, so CTPAV approached representatives of companies that already work with additive technologies and universities that have their own 3D printing research. Involved were also local authorities (National center for Industry 4.0) and Pilsen Region. Companies from various sectors - energy, automotive, tooling, healthcare, software development, aviation - took part in the workshops and gathered input for the roadmap. More experts were involved in the preparation of the roadmap update. We want to express our special thanks to:

- TECHNODAT, CAE-systémy, s.r.o.
- METAL3D s.r.o.
- Safran Cabin CZ s.r.o.
- Gühring s.r.o.
- Prusa Research a.s.
- Škoda JS a.s.
- Škoda Auto a.s.
- ProSpon spol. s r.o.
- COMTES FHT a.s.
- Západočeská univerzita v Plzni
- Regionální rozvojová agentura Plzeňského kraje
- Národní centrum Průmyslu 4.0
- Národní klastrová asociace, z.s.
- ONE3D s.r.o.
- Moravský letecký klastr, z.s.
- 3Dwiser s.r.o.
- NANOPROGRESS, z.s.
- Bayern Innovativ GmbH.

7. Workshop Output and Roadmap Recommendations

The output from the workshop has been reviewed and summarized in Tables 1 – 4. This overview provides the current status perceived in the Czech Republic in 2022, with the outlook on the future desired status in the region. It is important to note that this roadmap is essentially a live document, and these tables will likely change each year when reviewed.

The outputs from the workshop were captured manually as per the whiteboard exercise in Figure 20, then categorized into similar trends – for example in the Technology strand, the output was grouped into these subcategories:

- Modalities
- National Market
- Standards and Regulations
- Technology Blockers

Using these tables as a starting point, along with additional input and discussions during the workshop phases, the roadmap for three time-horizons has been created:

- **Horizon 1: Year 1 (Figure 25)** – High fidelity in terms of the tasks identified, both to resolve some short-term challenges, as well as to start the foundations for tasks that will expand into later horizons.
- **Horizon 2: Year 2-5 (Figure 26)** – Expanding on Horizon 1, but with less definition in the actions required.
- **Horizon 3: Year 5-10 (Figure 27)** - As per Horizon 2.

Finally, a summary roadmap for Years 1-10 has been created in Figure 28.

A key observation during the analysis stage is that many of the needs and requirements identified are not unique to the Czech Republic. For example, the need to drive towards an education and workforce development plan was highlighted during the workshop exercises, but the same need is identified in multiple national roadmaps (*UK, 2018*) (*Bayern Innovativ , 2019*) (*Bundesministerium, 2018*) and beyond. Although it is useful to benchmark the Czech Republic against other regions to identify where it may be possible to collaborate on some challenges, it is equally important to understand where there are unique aspects in the local area.

Table 1: Technology – Current Status and future Desired Status

Strand	Current Status	Desired Status
Technology	**Modalities**	
	Main AM modalities are polymer based: Filament Material Extrusion, Vat Polymerization, and Laser Powder Bed. Few metal AM machines are available in country (PBF-LB), primarily installed at universities. The medical sector will still use PBF technologies in the future.	Other AM modalities might become interesting in future (e.g., DED and BJT), if they mature and provide business opportunities currently not foreseen.
	National Market	
	Main market for AM is linked to automotive supply chain. Metal AM market is small and not competitive with traditional manufacturing. Additive Manufacturing of medical applications seems to be the only mature metal-based process; however, it is characterized of small quantities of custom products.	Open Czech Republic market to a global scale. Increase business opportunities by reducing or removing AM blockers and change mindset of budget holders by showing success stories and profitable business cases.
	Standards / Regulations	
	Limited awareness of standards for AM technologies at all levels.	Regulate AM as another production method
	Strong limitations in certifying AM parts within regulated industry sectors due to the poor knowledge of AM standards and regulations.	Adoption of AM standards and industry specific regulations to qualify and certify more AM parts, moving away from prototypes.
	Technology Blockers	
	AM technologies are generally perceived to be expensive, slow, non-mature and unstable compared to traditional manufacturing methods such as machining. Main blockers for market penetration are concentrated in the front end of the supply chain: AM machines, feedstock, software	Support maturation of AM technologies, being aware that technology limitations are not bounded to the Czech Republic; the global AM community is working to tackle them.
	Difficult to create profitable and reliable business models based on production of AM parts	Selection of appropriate business cases-based applications designed for the process
	Lack of qualified personnel	

Table 2: Applications

Strand	Current Status	Desired Status
Applications	**Main Applications**	
	Main applications are prototypes and production jigs Current applications will remain in the future	Introduce more applications if the following blockers will be removed: costs, lack of regulations, lack of skilled personnel, poor equipment stability and low TRLs compared to other traditional manufacturing technologies
	Industry users need to see success stories of AM applications and consider it as another manufacturing process	Adopt more AM parts in regulated industries such as nuclear and aviation
	Very few organizations are pushing towards the adoption of AM in general	Exploit AM in less regulated industry sectors such as tooling and repair
	Materials	
	There is a lack of guidance on AM materials selection	Comprehensive characterization of commercially available AM material formulations.
	Actual AM materials are not well understood	Robust understanding of functional behavior of AM parts in service.
	Companies are reluctant to use AM parts rather than for prototyping needs since there is a poor knowledge of parts failure modes and material defects	Clear guidelines on AM materials selection to fulfill functionality and economical aspects
	A comprehensive characterization of commercially available AM materials should be completed first, before moving to develop new optimized formulations	Develop and characterize AM optimized material formulations Characterize process-structure-properties relationship for AM materials
	Environmental Considerations / Recycling	
	Future AM applications should consider recycled feedstocks when possible. AM should carry a positive message when looking at environmental aspects	AM should carry a positive message when looking at environmental aspects

Table 3: Infrastructure

Strand	Current Status	Desired Status
Infrastructure	**Supply Chain Mapping**	
	A map of the Czech Republic supply chain is not available	Updated map of the AM supply chain in Czech Republic, to be published in every revision of the technological roadmap.
	Large OEMs use primarily AM to manufacture jigs to support production.	OEMs to adopt AM technologies to manufacture parts for Nuclear, Aviation and other regulated sectors
	Most AM users are service bureaus operating polymer AM machines.	Introduce more industrial AM machines, in particular for metal printing
	Available Post - Processes	
	The following technologies and processes are mature in Czech Republic: Material Testing, NDT, CT Scanning, Metrology. The country has also strong simulation and modelling capabilities.	Leverage national strengths in the AM supply chain to achieve leading position in Central/East Europe
	In-Situ monitoring is seen as a research activity and has currently a very low TRL	
	Outsourced Post-Processes	
	Hipping HT, surface enhancement treatments, powder removal processes and feedstock production are outsourced	All the main supply chain equipment and related expertise should be available throughout the country
	AM Infrastructure Limitations	
	AM users should be supported to adopt AM technologies that still present low TRL levels compared to other well established manufacturing methods	Great awareness Quality Management and associated aspects regarding AM AM users accredited according to relevant industry standards
	Companies are well equipped with CNC machining facilities and can generate consistent profits that cannot be achieved with AM.	Complementary adoption of AM technologies with traditional manufacturing methods
	There is currently a low level of technology transfer and communication between central HQs and subsidiaries located in Czech Republic. The main knowledge is held in central facilities	OEMs to open AM facilities in Czech Republic
	There is generally a low experience and expertise on several quality related subjects for AM; some examples: implementing AM into a QMS, how to achieve a company	

	quality accreditation in AM, how to maintain an AM facility, how to manage liabilities of AM parts	
	Make or Buy AM Parts	
	The cost of setting up a production AM facility is prohibitive AM related subjects is self-taught within companies Industrial AM machines are still expensive investments and companies struggle to make profits	Implementation of proper business models tailored for ideal AM applications Industrial AM machines should meet CNC machines prices in the future

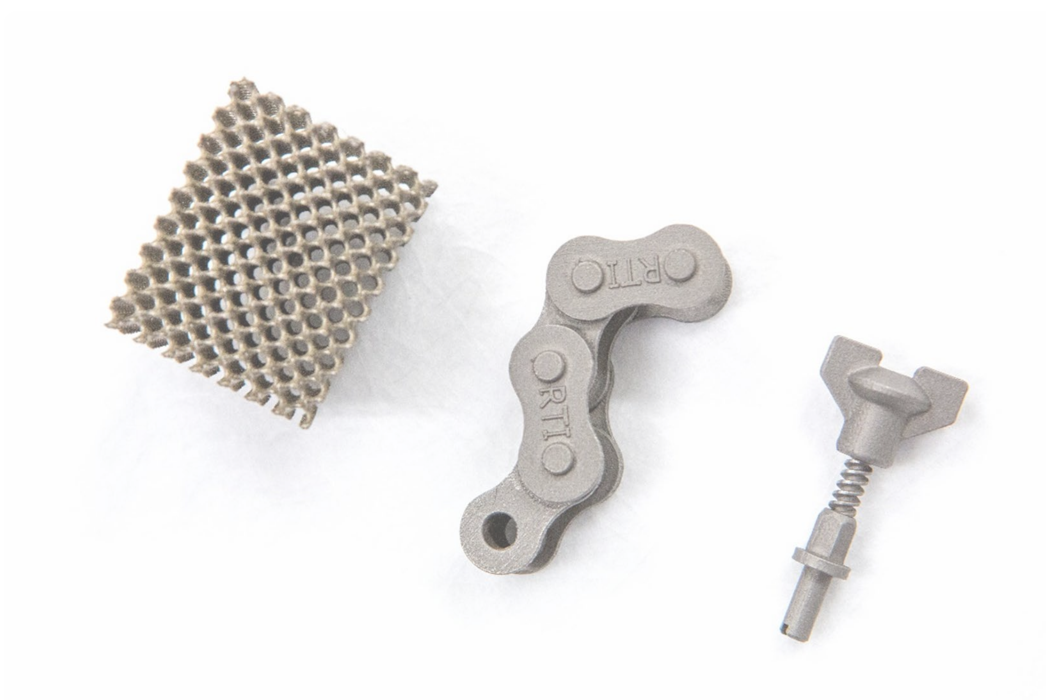


Table 4: People

Strand	Current Status	Desired Status
People	**AM Workforce**	
	There is lack of skilled engineers in AM AM related subjects is self-taught within companies	Availability of a certified and skilled workforce for AM, covering all the necessary roles that should be defined
	The is a lack of hands-on AM experience	Trainings offered by accredited organizations, external from companies using the technology
	Subjects Needing Urgent Support	
	Need to improve knowledge on DFAM, Qualification and Certification of AM parts Understanding of parts requirements versus AM process capability is missing There is a poor knowledge of risk-based analysis for AM	Design for Additive Manufacturing (DFAM) should be given the highest priority when strengthening the AM workforce expertise, followed by Qualification and Certification subjects
	People Mindset	
	A change in people mindset in favor of AM is needed at all levels, starting from budget holders and decision makers.	Budget holders and decision makers to approach AM in a fair way, supported by the right education and success stories
	AM is still seen as a limited manufacturing method, mainly because of costs	AM to be a viable manufacturing option in parallel with other traditional methods AM seen as a production method
	AM in the education system	
	AM subjects are briefly covered in master's degree University Courses	AM should be introduced at all education levels from schools to universities A dedicated curriculum for engineering students should be established
	Funding and Engagement	
	There is currently a poor engagement among AM users in Czech Republic	AM users should have frequent occasions to meet at events to share experiences
	Government funding towards AM subjects are little and should be improved	Collaboration should prevent competition in some extent to accelerate AM adoption

8. 1st year update

The first reactions to the roadmap came immediately after its publication. Industry in the Czech Republic has its own specifics, among other things, in that many major companies and industries are linked to large global concerns and work with new technologies is guided by a multinational strategy. During discussions with many experts, we have identified the aerospace and healthcare sectors as progressive fields for further development of additive technologies and the activities of the CTPAV.

Industrial Ecosystems and Additive Manufacturing

Industrial ecosystems are a concept that has recently resonated in the European area. 14 basic ecosystems have been defined, within which innovative ideas and probably also most R&D projects will continue to be supported.

- Aerospace & Defence Ecosystem
- Agri-Food Ecosystem
- Construction Ecosystem
- Cultural & Creative Industries Ecosystem
- Digital Ecosystem
- Electronics Ecosystem
- Energy-Intensive Industries Ecosystem
- Energy-Renewables Ecosystem
- Health Ecosystem
- Mobility-Transport-Automotive Ecosystem
- Proximity, Social Economy & Civil Security Ecosystem
- Retail Ecosystem
- Textil Ecosystem
- Tourism Ecosystem

In the Czech environment, this is a new topic, which has also been elaborated in detail by the National Cluster Association for the needs of its member cluster organizations and companies associated in clusters. From the perspective of future European policy, it is important to spread knowledge of these ecosystems among Czech companies. Additive manufacturing by its very nature is intertwined with most of them and is therefore an appropriate supporting theme.

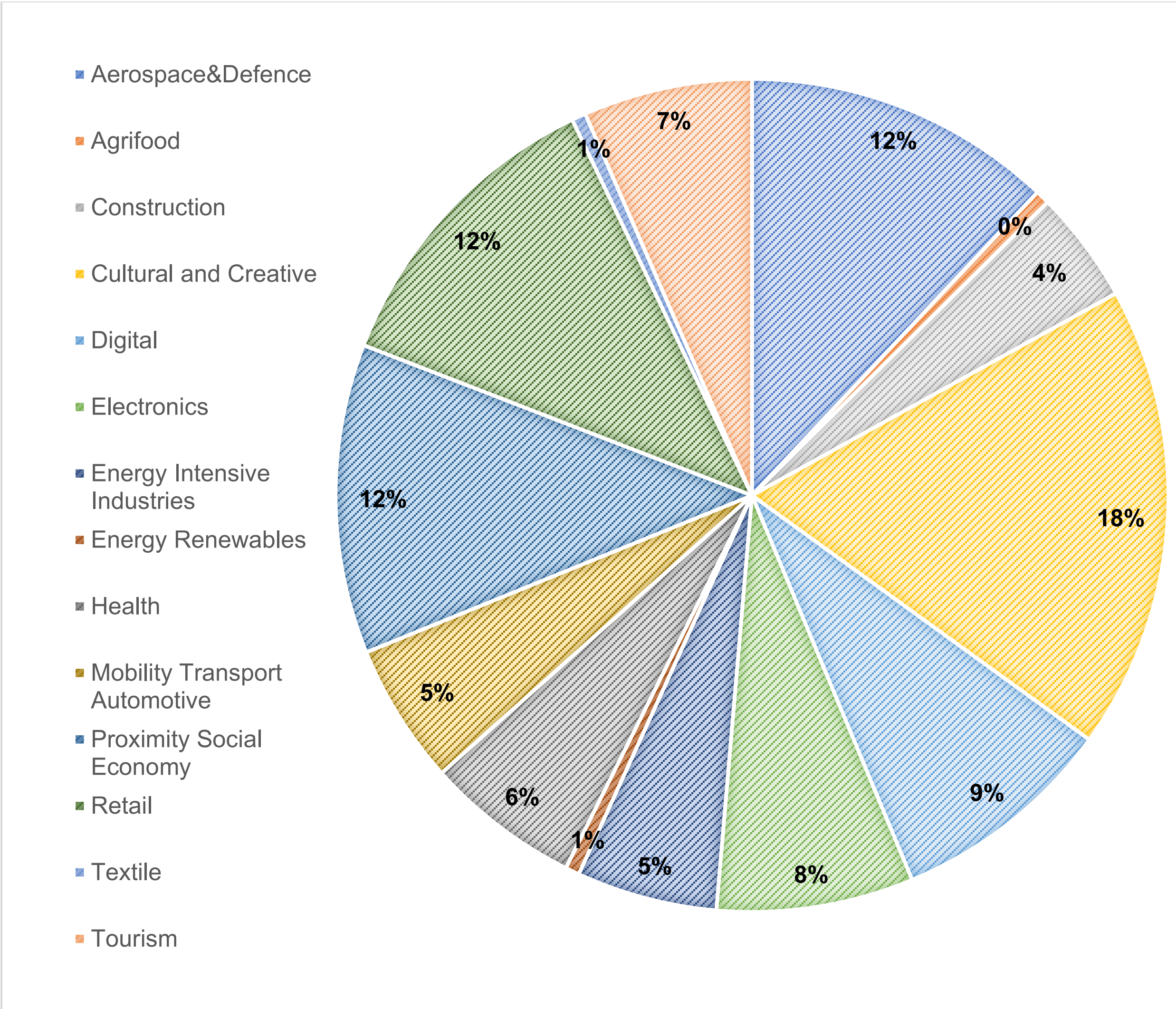


Figure 21 – Czech Companies & Industrial Ecosystems, NCA

Additive manufacturing has become increasingly important technologies in various sectors of industrial ecosystems due to their flexibility and ability to create unique and customizable products. These technologies can be used in many different fields, including healthcare, construction, automotive, aerospace, fashion, research and development, and many others.

In the medical industry, AM is used to produce models of organs and tissues, dentures, orthopedic implants, and prosthetics. In the construction industry, it is used to print concrete and metal parts and objects. In the automotive industry to print spare parts and to produce prototypes. In aerospace, AM is used to manufacture aircraft components and engines. In the fashion industry, it is used to produce jewelry and accessories, as well as to create unique clothing and footwear. In research and development, AM is used to produce prototypes and to test new concepts.

So, in each industry, additive manufacturing is used in different ways, whether it's for prototyping, making unique products, or producing spare parts. As this is a relatively new technology, it is likely that it will continue to be developed and further opportunities offered by this technology will be exploited. Specifically, additive manufacturing is in a sector of the industrial ecosystem called Advanced Manufacturing. This includes a wide range of technologies such as robotics, digital manufacturing, IoT, AI and more. These technologies enable the industry to produce more goods in less time and at less cost. The NACE industrial classification is a **standardized** classification of economic activities that divides the economy into sectors, branches and sub-sectors.

Selected companies appear in NACE mainly in the following sectors: Aerospace & Defense, Cultural and Creative, Digital and Electronics. In terms of NACE codes for the selected firms, Retail and Proximity Social Economy appear, but this appearance is irrelevant and related to the broader focus of the individual firms. It is important to keep in mind that the selected companies are just an example and that there will be many more companies using additive manufacturing emerging in other industries in NACE. However, these results provide valuable insight into how these technologies are being used in the industrial sector.

The results of conducted survey show that additive manufacturing have become an important part of industries that focus on producing technologically advanced and customizable products. These technologies are used to produce innovative parts, prototypes and spare parts for various industrial sectors. It further shows that additive manufacturing is not limited to one industry but can be used in a wide range of industries. The results also show that additive manufacturing is playing an increasingly important role in moving industry towards more sustainable and efficient production.

Projects and Education

This roadmap has the ambition to be a practical strategic document. For the updated version, a survey of implemented R&D projects with additive manufacturing themes was carried out. Its aim was to confirm the fields that were identified as important and with potential for further development.

One of the strategic directions we have defined from the beginning is education. Although additive manufacturing is well-known in the Czech environment, there are over 10 official study programmes dedicated to additive technologies, which is not much. This is despite the fact that all major universities and colleges in the Czech Republic work with this field in some way. In the field of continuing education, there are several courses (online and in-situ) where those interested can acquire the necessary skills. There are also "hobby" courses in various makerspaces for the wider public.

Over 130 R&D projects on the topic of additive manufacturing have been solved or are being solved in the Czech Republic in recent years. Most of them are dedicated to specific topics (new product, improved technology) in the fields of engineering and medical sciences. almost all of them involve specific Czech industrial companies interested in expanding their competences and strengthening their competitiveness. Only a few projects have also been dedicated to the popularisation of this topic.

Additive Manufacturing in aviation: a revolution in manufacturing and design

Why is the use of AM in aviation so groundbreaking? Mainly because of the weight savings. By reducing the weight of an aircraft by 1kg, it is possible to reduce its carbon dioxide production by up to 25t per lifetime. Yet CO2 production from aviation accounted for 2,5% of global production in 2020 and the trend was significantly upwards.

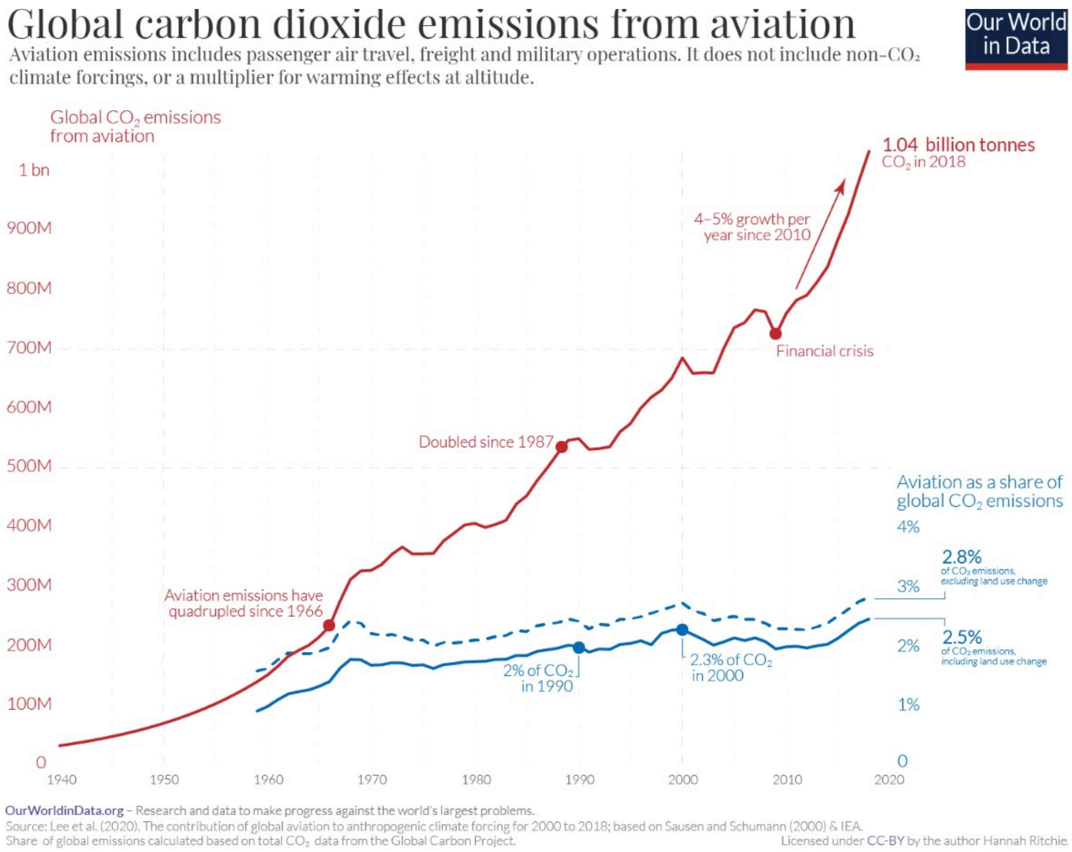


Figure 22 - CO2 emissions from aviation, H. Ritchie – Our World in Data

The use of additive manufacturing in aviation brings several advantages. The first is the possibility of weight reduction and optimization of structures. With additive technologies, it is possible to create components with complex geometries that allow weight reduction without compromising strength. This can lead to reduced fuel consumption and increased aircraft efficiency - i.e. reduced emissions. AM makes it possible to unify multiple parts of an assembly into a single piece. This simplifies assembly during aircraft production and further reduces the risk of breakage at the joint.

While there are many benefits to AM, there are also risks and challenges to consider. One potential risk is the difference between additive manufactured materials and conventional ones. At first glance, they may appear to be the same material, but due to the different processing of the material, there may be a different internal structure within the material, which can cause different mechanical properties. It is therefore important to carefully select materials and optimize printing processes to achieve the desired part quality.

Despite the aforementioned risks, additive manufacturing finds applications in various areas of the industry. It is estimated that up to 75% of aircraft produced by 2021 will have some component produced by additive technologies. A specific example of AM optimization is used for a door hinge in the Airbus A350. Here, 45% of the hinge weight was saved through optimization and additive technologies, which is about 4 kg for the 16 door hinges that the A350 is fitted with.

Figure 23 – Comparison of printed and conventional part, Airbus

The use of additive technologies in aerospace brings a number of benefits such as weight reduction, shorter production times, reduced costs and the possibility of customization. However, there are also risks and challenges that need to be addressed.

For the expansion of additive manufacturing in aerospace, standards need to be ensured so that it is clear what quality parts are being produced. The aerospace industry is conservative towards new technologies, particularly due to high safety requirements. To widely accept the new technology, a large number of tests will have to be carried out to increase confidence among aircraft manufacturers in this revolutionary technology.

Additive manufacturing is already widespread in aviation and finds applications in various areas such as engine parts, lightweight structures and cabin components. Various materials such as titanium and polymers are used in the manufacturing process and there are several 3D printing technologies suitable for aviation. However, there remains a wide scope for the application of these technologies. By applying more 3D printed parts, it could be possible to further reduce the weight of aircraft and thus reduce their emissions. AM is a revolutionary technology in aviation, enabling innovation in aircraft design, manufacturing and construction. With further advances in this field, the use of additive technologies in aviation is expected to continue to grow and bring further benefits and opportunities.

Additive Manufacturing for the healthcare industry

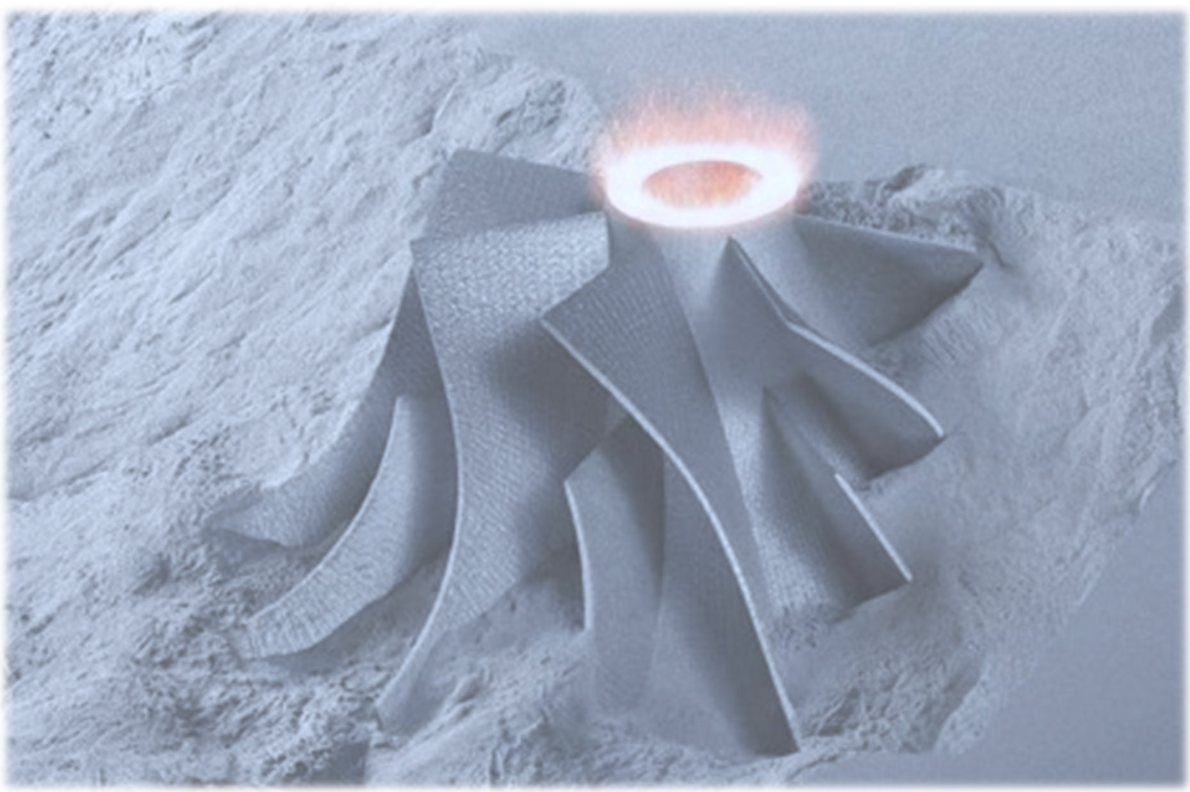
Additive Manufacturing represents a paradigm shift in healthcare. This pioneering technology offers several advantages that can significantly enhance medical care and medical research, thereby improving patient treatment and the delivery of healthcare services.

The key advantage of AM in healthcare lies in its ability to enable the production of customized medical devices in a short time interval. Each patient's anatomy is unique and often requires individually tailored tools to achieve optimal treatment outcomes. Traditional manufacturing techniques struggle to effectively meet these specific requirements, but additive manufacturing excels in this regard. Using data from advanced medical imaging techniques, such as magnetic resonance imaging or computed tomography, 3D printers can produce a variety of customized products, with the result being perfectly customized, increased treatment efficiency, and improved patient comfort. AM is also an important tool in surgical planning and physician education. Surgeons can use 3D printed models of the patient's affected area before performing the actual surgery. This hands-on approach facilitates a deeper understanding of the complexities of the procedure, thereby reducing surgery time and risk and improving surgical outcomes in general.

The use of additive manufacturing can be found in several medical specialties, including orthopedics, implantology, audiology and especially dentistry. The introduction of AM abroad has already revolutionized dentistry and has enabled dentists to design and manufacture customized dental implants, crowns, bridges, braces, etc. in the office. This option leads to faster creation of the desired customized products, higher precision in processing and less stressful situations for patients.

Figure 24 - printed orthoses for children & teenagers, UWB

Looking to the future, the potential of AM in healthcare is huge as it can be a tool for improving and speeding up medical care. This is also supported by the fact that there is already a range of additive technologies and a huge amount of biocompatible materials available that can be used for the healthcare sector. Of particular interest are developments in the field of 'bioprinting' (3D bioprinting). Although this technology is still in its early stages, the implications are already expected to be significant, as it could alleviate dependence on, for example, organ donation and provide new hope for many patients. In the future, we may see AM contribute to the development of intelligent medical devices capable of delivering drugs or monitoring patients, heralding a new era of personalized medicine. In the US, for example, additive technologies are already widely integrated into the healthcare system, enabling the creation of customized prostheses and implants, facilitating surgery planning and speeding up dental procedures. Adapting these procedures in the Czech Republic requires careful orientation in regulatory standards, development of technical knowledge of medical personnel, establishment of synergistic cooperation with research institutions and allocation of necessary financial investments for equipment, materials and training. Although these challenges may present some obstacles, the introduction of additive manufacturing into the Czech healthcare system represents a transformational opportunity to improve patient care and the overall efficiency of a number of healthcare processes.

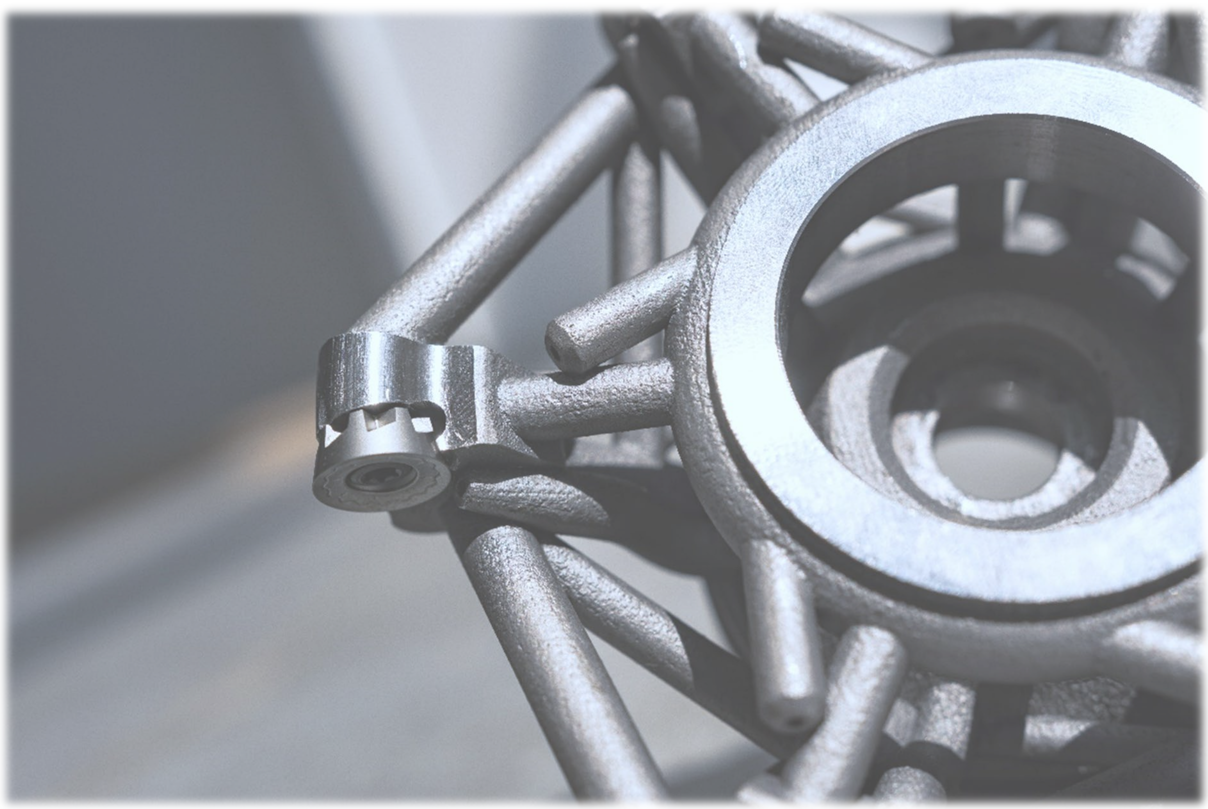


9. What´s next

We have mapped the cases, we have confirmed that the fields we have mentioned as key are indeed key, because that is where most projects are headed. We want to continue to support them, at least with information and awareness.

In cooperation with the aviation cluster, we are preparing a project that will help define the Czech certification process for printed parts. We continue to look for new ways to use additive technologies and deploy additive manufacturing in the Czech industrial environment. Interest in the state of additive technologies in the Czech Republic is also growing internationally. In 2023, the Wohlers Report will also focus on additive technologies in the Czech Republic for the first time.

On the following page we present an evaluation of the first year of the life of the roadmap (swim lines). In cooperation with other partners, we are ready to continue the implementation of the individual tasks and steps.



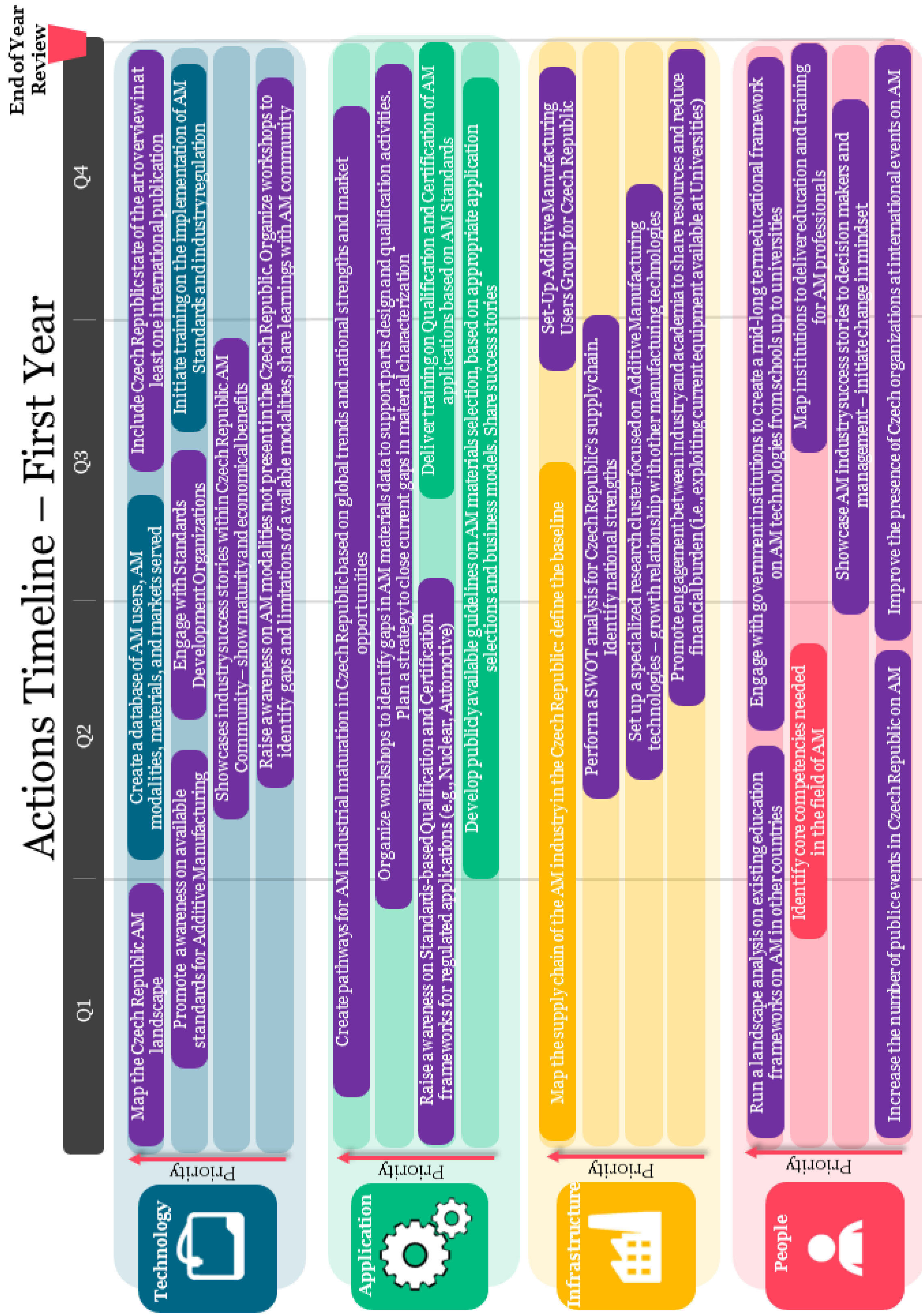


Figure 25 – Completed 1st Year Actions

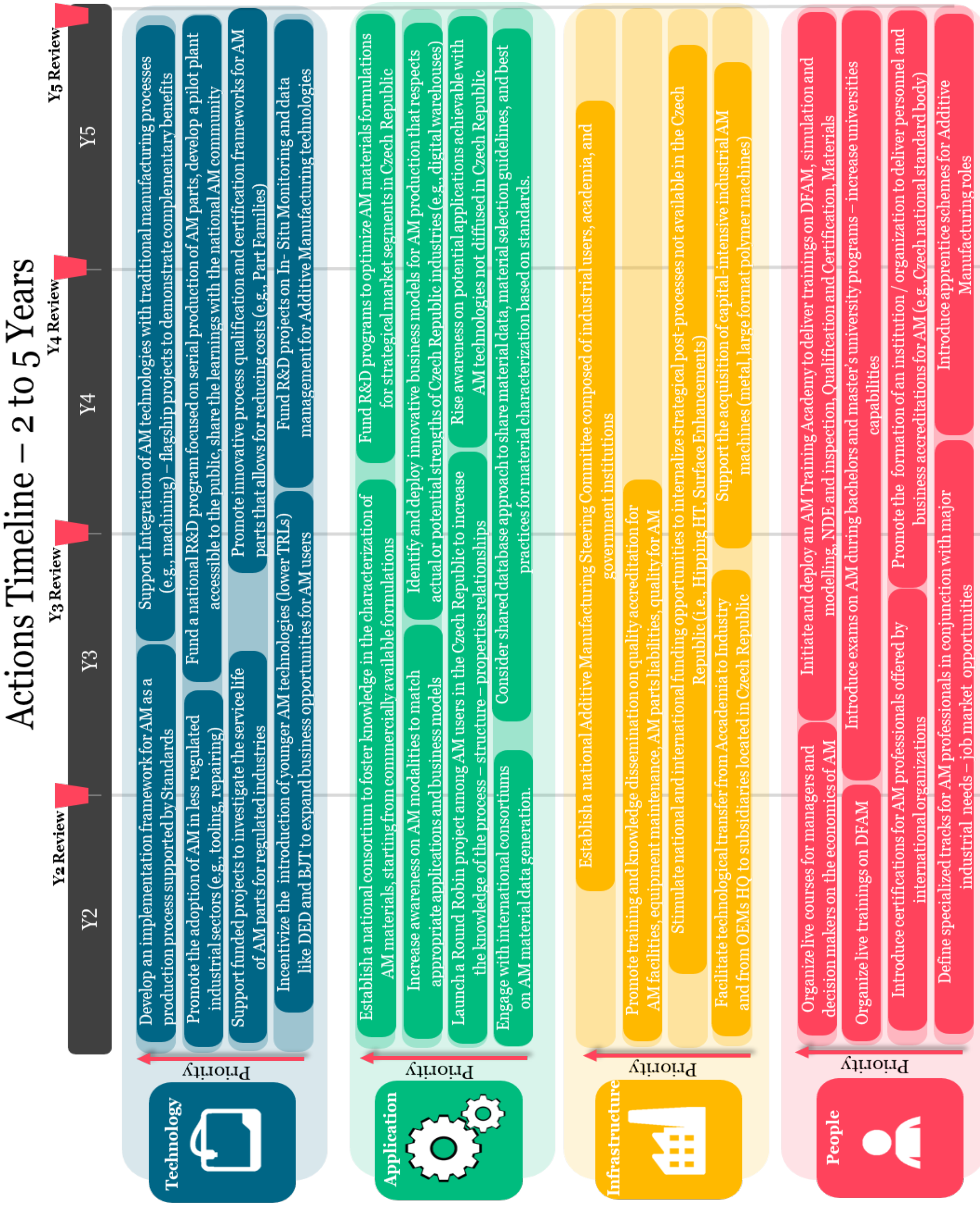


Figure 8 – Actions for years 2-5

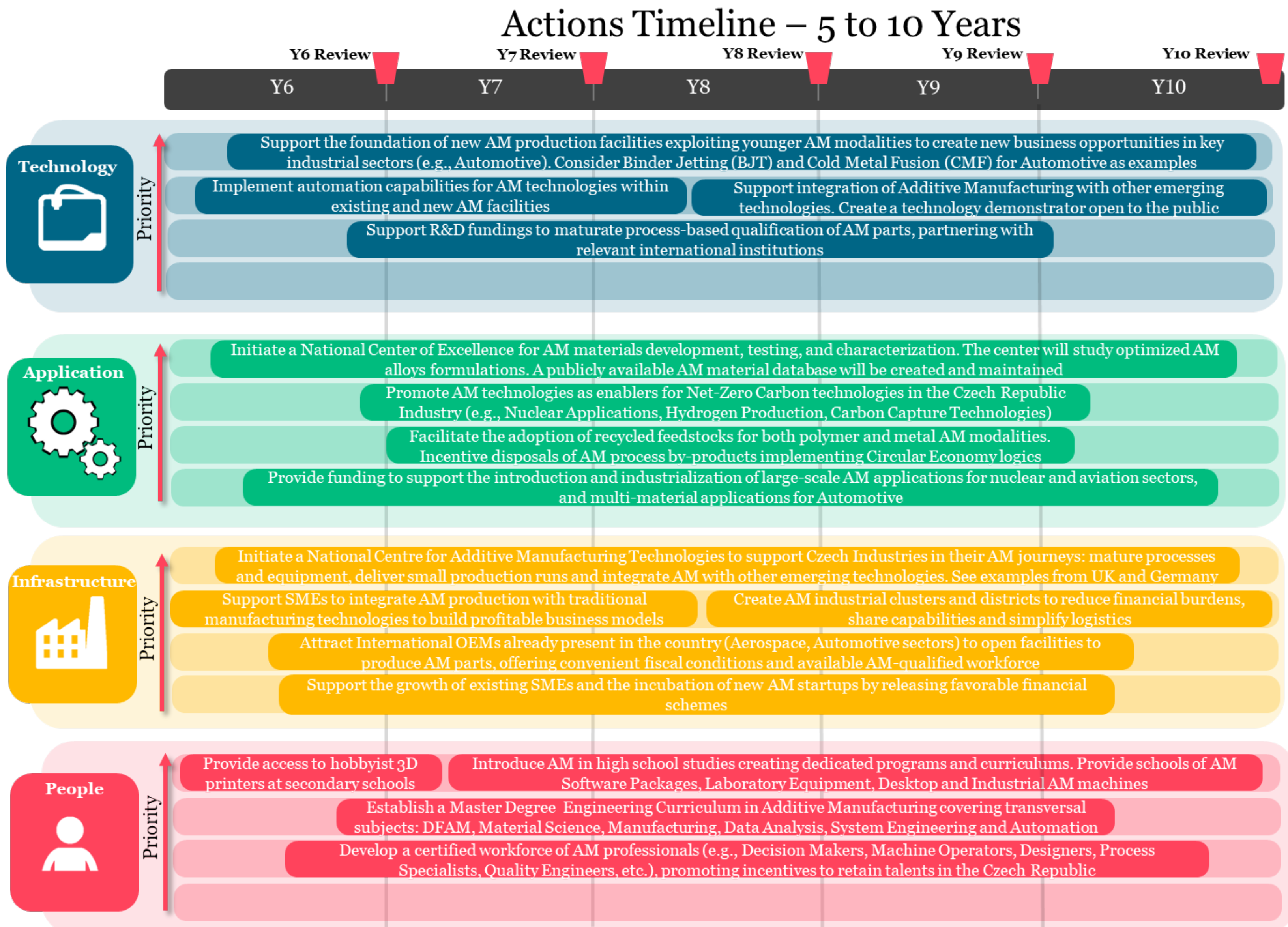


Figure 9 – Actions for years 5-10

Actions Timeline - 10 Years Summary

	Year 1	Years 2-5	Years 5-10
Technology (Priority)	Landscape mapping of AM modalities	Implement AM technologies as a complementary production method supported by standards and regulations	Establish new AM production based on developing AM modalities (i.e. CMF, BJT) for strategic markets
	Increase awareness of available AM Standards	Foster adoption of AM technologies in less regulated sectors (i.e., tooling). Promote learnings on AM serial production	Implement automation for AM production processes and support integration with other emerging technologies
	Identify gaps and limitations in main AM modalities used in CR	Increase awareness on the mechanical behavior of AM parts in service and on qualification and certification	Support implementation of more efficient qualification and certification frameworks (part family, process-based)
	Showcase industry success stories and business models	Promote introduction and development of less mature AM technologies for strategical markets (i.e. Binder Jetting)	
Application (Priority)	Create pathways for industrial maturation of AM	Establish a consortium among AM users to characterize commercially available AM materials	Institute a National Centre of Excellence for AM materials development, testing and characterization
	Identify gaps in knowledge of AM materials	Support the generation of appropriate business models for AM / right application selection	Support adoption of AM technologies to enable Net-Zero carbon technologies by funding dedicated projects
	Train AM users on Qualification and Certification of AM parts	Fund R&D projects to rise awareness of process-structure-properties relations for AM applications	Introduce incentives to adopt recycled feedstocks for AM production and to deploy circular economy
	Generate public guidelines on AM materials selection	Generate online databases on material characterization, AM processes, provide guidelines	Support the industrialization of AM multi-material applications
Infrastructure (Priority)	Comprehensive mapping of the national AM supply chain	Establish and develop a National Additive Manufacturing Steering Committee	Institute a National Centre for Additive Manufacturing Technologies to support Czech Industries on all aspects
	Perform SWOT analysis on AM supply chain – set expansion plan	Achieve Quality Accreditations for AM facilities supported by trainings. Raise knowledge of quality for AM	Create business parks and clusters of AM companies, in the proximity of large OEMs
	Set Up a national research cluster on AM technologies	Support fundings and offer favorable financial solutions to internalize post-processes and grow the AM supply chain	Attract International OEMs to open production facilities for AM parts, offering convenient fiscal conditions
	Promote engagement between AM users and Academia	Improve technological transfer between Accademia and Industry and between OEMs HQ and Czech subsidiaries	Support the growth of existing SMEs and the incubation of new AM startups by releasing favorable financial schemes
People (Priority)	Create a mid-long educational framework for AM	Initiate and develop a national Additive Manufacturing Training Academy. Deliver accredited trainings	Introduce AM as a subject in high school studies delivering dedicated programs. Provide hobbyist 3D printers in schools
	Identify core competencies needed in the field of AM	Introduce courses on AM during bachelor and master university programs – increase university capabilities	Establish a Master Degree University Course in Additive Manufacturing
	Promote change in mindset towards AM for decision makers	Establish and develop an organization to deliver personnel and facility accreditations for AM	Develop a certified workforce of AM professionals. Provide schemes to retain skilled talents in the country
	Increase national events on AM and international visibility	Define recognized curriculum for AM professionals, introduce dedicated apprentice / internship schemes	

Figure 10 – 10 Year Summary Table

10. Summary

This is the first update of Czech roadmap for additive technologies in the Czech Republic. This update was planned within the mentioned project CTPAV. Our aim was to add new topics which have the potential for further development of additive technologies in the Czech Republic and the implementation of the Roadmap activities. The Roadmap is compiled as a strategic document that defines the basic directions for additive manufacturing. The basic theses are valid in the long term and in the following years it will only be necessary to evaluate the progress in individual topics.

We still believe that the very existence of this RM will show the Czech Republic as a country that is strategically working with advanced technologies. At the same time, the RM serves as a working basis for the public sector, i.e. schools and universities, and for their specialization of disciplines. Furthermore, it also offers the public administration many impulses for the creation of grant programmes and support directed to enterprises to help the development of Czech industry.

This roadmap and its update were created within the framework of the project of the CTPAV (reg. No.: CZ.01 .1.02/0.0/0.0/20_369/0025091), which is supported by the EU through the Operational Programme Enterprise and Innovations for Competitiveness and will undergo its first revision in 2023. We are sure that in this first revision we will add further suggestions from the academic and industrial sector to create a strong strategic and long-term document that will support the development of additive manufacturing in the Czech Republic and show the Czech Republic as a country that is not only not afraid of progressive technologies, but also knows how to work with them systematically.

EVROPSKÁ UNIE
Evropský fond pro regionální rozvoj
Operační program Podnikání
a inovace pro konkurenceschopnost

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