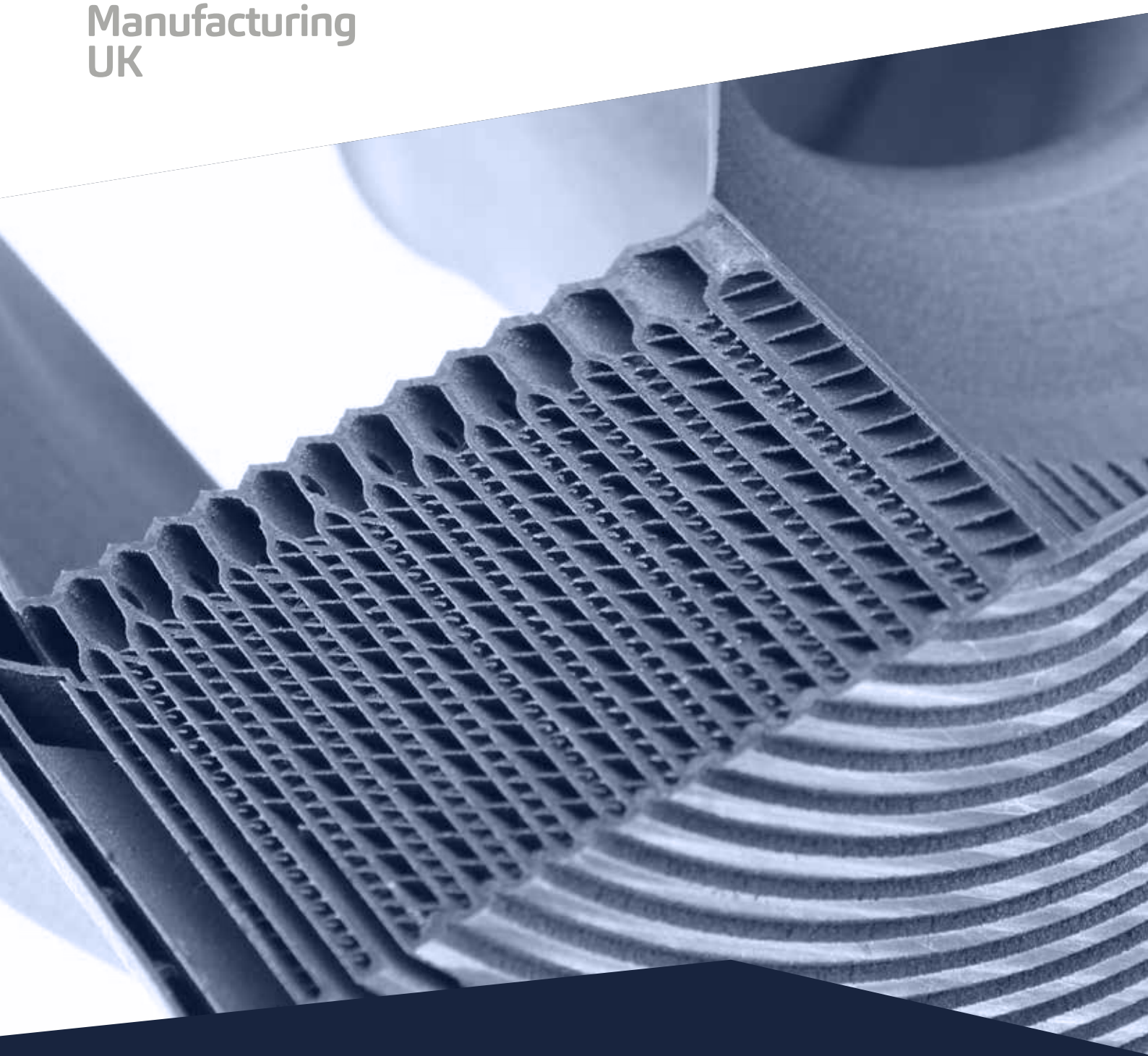




Additive
Manufacturing
UK



Additive Manufacturing UK

National Strategy 2018 - 25

Leading Additive Manufacturing in the UK



Foreword



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Chair, Innovate UK



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The potential benefits to the UK economy of the wider adoption of additive manufacturing technologies are clearly huge. These technologies provide the capability to transform and enhance product development and production in a wide range of sectors and applications, enable the reconfiguring of supply chains allowing production close to the point of consumption, and deliver the benefits of mass customisation.

As a digitally-enabled technology, additive manufacturing is an essential element within the rapidly changing context of industrial digitalisation. If we can ensure that the UK is able to build a strong position in the development and adoption, of additive manufacturing within that context, this will help ensure the UK is well positioned to unlock the even more substantial benefits of industrial digitalisation.

This strategy clearly shows the UK has the ability to create and capture substantial value from the continued development and wider adoption of additive manufacturing technologies. The recommendations given in this strategy provide clear guidance for the removal of the barriers to adoption so the potential is made a reality for the benefit of the UK economy. I strongly endorse this strategy and look forward to seeing these recommendations implemented.

Today, additive manufacturing is no longer an aspirational technology, it is a 'Must Have' for the UK's High Value Manufacturing sector to remain competitive globally. This national strategy provides recommendations to enable UK industry to unlock the full commercial potential of additive manufacturing and presents the output of three years of work undertaken by the UK AM community.

From an industrial perspective, whether it be a long-established manufacturing business or a newly emerged start-up, there are many adoption challenges that need to be overcome to de-risk and scale-up the rapidly evolving additive manufacturing technologies. Although it is widely recognised that the UK is one of the leaders in world-class research and innovation in additive manufacturing, it is falling behind in its commercialisation. The UK requires a co-ordinated, sustained and cross-sectorial approach to pull-through the research and innovation, to enhance process effectiveness and efficiencies, to strengthen the supply chain, to protect IP and to enable industry to access finance. As presented here, a set of cross-sector thematic working groups have developed a series of wide-ranging recommendations that require UK government funding alongside the substantial investment committed by UK industry.

High Value Manufacturing is the life-blood of UK industry, contributing to more than £100bn GVA and employs over a million skilled people. We have world-beating UK companies across a range of sectors and to support them as we move into a new digitally enhanced technological world, the nation must act swiftly and decisively to accelerate the adoption and integration of additive manufacturing.

Executive Summary

Additive manufacturing, also known as 3D printing, creates objects by adding layers of material one on top of another. It is starting to transform the way companies design, manufacture and even supply their products and presents an opportunity to radically change a variety of manufacturing business models.

The UK has world-class additive manufacturing experience in research, design and manufacturing expertise. We can build on this to alleviate the threat to our high value manufacturing sector. The potential of additive manufacturing for UK companies is widely recognised, with an expected industry investment of £600m over the next five years.

There is a significant opportunity for the UK to gain considerable market share of a worldwide market for all additive manufacturing products and services, which in 2017 was estimated to be over £6bn and growing rapidly. Whilst the directly attributable value of additive manufacturing products and services is currently a more modest £300m, it is experiencing a steady annual growth of around 30% and this is expected to accelerate as issues of standards, material consistency, IP protection and parts verification are addressed. However, this additive manufacturing share represents less than 0.05% of the world market for manufacturing (\$11.4 trillion) and the opportunities presented as additive manufacturing becomes more broadly adopted are substantial.

The UK's High Value Manufacturing sector can capture over £3.5bn per year (gross value added, GVA) for the UK of the rapidly growing global market for additive manufacturing derived products and services by 2025, supporting 60,000 jobs in the knowledge economy and generating new, highly skilled employment opportunities. To meet this vision, this strategy has been developed to upgrade competitiveness, increase productivity and accelerate innovation in the UK. With the right support, the technology will lead to significant global export opportunities across all sectors engaged in High Value Manufacturing (HVM).

Despite the exciting potential and progress to date, many UK companies, especially within the SME community, lack the awareness, resources or confidence to apply additive manufacturing as a core and integral part of their manufacturing toolkit. A recent global survey conducted by Ernst and Young showed that only 17%

of UK companies have any experience with additive manufacturing, compared to 37% in Germany and 24% in China. This is a serious threat to UK manufacturing and specifically to the High Value Manufacturing sector, which if it does not adopt additive manufacturing will be at great danger of losing significant ground in this sector by 2030.

The nation's manufacturers-small, medium and large-across the sectors urgently need a unified approach to address shortfalls in the commercialisation of additive manufacturing. Like many other countries who are instigating major programmes to introduce additive manufacturing into their supply chains enabling the UK to become the leading nation for exploiting high value additive manufacturing. Cross-sector thematic working groups under the auspices of AM UK have identified the main barriers, market failures and burdens currently inhibiting the full and rapid commercialisation of additive manufacturing in the UK. In order to advance rapidly with commercialisation, AM UK identifies in this strategy the required essential cross-sector activities that need to be delivered through the UK's established, knowledgeable and expert infrastructure. This challenging strategy must be supported by public funding to the order of £225m over the next five years in order to make the material impacts identified possible.

The UK must take decisive action quickly if it is to compete globally as a leading High Value Manufacturing nation: the life-blood of manufacturing in the UK.

A full set of recommendations is presented within this strategy, as developed by the thematic working groups, covering the following focus areas:

Technology

Support for up-scaled collaborative and private R&D programmes across the entire Technology Readiness Level (TRL) range, addressing the broad value chain of additive manufacturing: raw materials through to final part qualification and end-of-life requirements, as well as addressing the crucial 'Design for AM' aspects – principles, practices and tools.



Skills and training

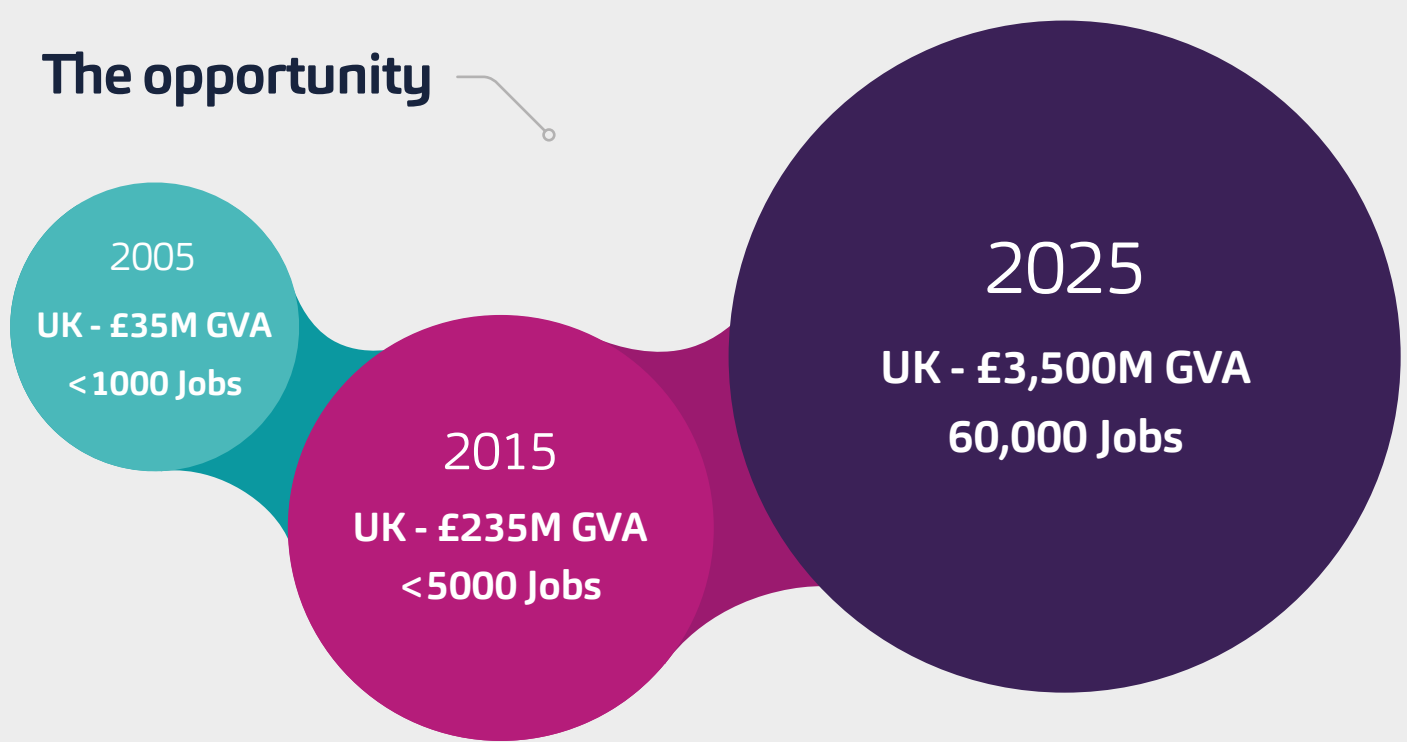
Addressing the skills gap by supporting the creation of specialist additive manufacturing education programmes, at all levels. These include apprenticeships, on-line training courses, further education and in-work re-skilling programmes. Supporting industry and trade associations in raising awareness of the capabilities (and limitations) of additive manufacturing.

Business support and supply chain development

Secure the production of physical additive manufacturing assets in the UK by providing (for example) capital grants for investment in additive manufacturing machines, as well as the development of relevant commercial instruments. Establish a platform for the development and sharing of best practices, relevant standards and appropriate IP protection.



The opportunity



Industrial support

This document has been prepared by the UK Additive Manufacturing Steering Group, a representative group of business, research and leadership personnel with expertise in the domain. Reference Appendix 3.

Continuing support from the industrial leaders involved is also acknowledged:

Philip Dell’Orco

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President and CEO

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Rob Sharman

Global Head of Additive Manufacturing

[GKN Aerospace Services Limited](#)

Sir David R McMurtry

Chairman and Chief Executive

[Renishaw plc](#)

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Director of Global Manufacturing

[Rolls-Royce plc](#)

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Director

[Sebastian Conran Associates](#)

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R&D Packaging Vice President

[Unilever plc](#)

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Our Vision

The vision is to drive the UK to the forefront of commercialised additive manufacturing, supporting the High Value Manufacturing sector that is the life-blood of the UK's manufacturing industry. It is estimated that by 2025 this will generate over £3.5 bn per year GVA, and support 60,000 jobs across additive manufacturing and its share of the knowledge economy.

The specific aims of the vision are as follows:

- Address identified technology and market barriers that impede the rapid commercialisation, competitiveness and productivity of the whole additive manufacturing supply chain
- Devise and deliver the training and education programmes needed to provide additive manufacturing engineers for today and for the future
- Help industry to exploit the competitive advantage to be gained by using additive manufacturing for prototypes, tooling and end-use parts
- Develop additive manufacturing techniques, materials, inspection processes and standards to deliver outstanding results at industry-leading quality at scale
- Provide the necessary infrastructure to help industry obtain commercial benefits from additive manufacturing
- Create a 'showcase' for additive manufacturing to demonstrate how well it works in practice, supported by regional support as appropriate
- Develop a strong network of additive experts in the UK and support knowledge transfer
- Help industry to access public funding and grants
- Continue to undertake detailed market analysis to identify the opportunities, barriers and impacts
- Attract funding, leveraging both private and public sources, to pursue opportunities enabled by research and innovation

CASE STUDY

Johnson Matthey Additive Manufacturing

Johnson Matthey has invested heavily in cutting-edge technology to deliver tailored ceramic products with flexible geometries and feature sizes down to just 400µm. This process is fully scalable, offering a cost-effective solution for producing small, complex ceramics on a large scale. Our state-of-the-art analytic laboratory ensures exceptional precision and quality throughout.

Cutting edge technology:

- Materials can be screened quickly for printability
- Prototypes can be easily developed and refined
- Products are characterised to suit their end use

Customised Geometries:

- Complex shapes with feature sizes down to 400µm
- Customised approach to benefit specific applications, such as increasing surface area or reducing pressure drop in fluid systems

Material Flexibility:

- Ability to trial and print, using a variety of different materials and developing new recipes with very small quantities of ceramics, depending upon the application

www.matthey.com



AM UK - Who we are

AM UK is an independent, government-supported collaboration, positioned to help create, disseminate and drive the UK's additive manufacturing strategy.

Established in 2014, the group has led extensive UK-wide consultations and workshops, with guidance and advice from an established set of 10 Industry Captains. AM UK published its first work in March 2015 - a positioning paper entitled: 'The Case for Additive Manufacturing'.

The group has further engaged with over 100 experts from industry, academia and professional bodies. The engagement was structured around seven cross-sector, thematic working groups. They have worked to provide informed insight into the opportunities, barriers, strengths and the threats that currently inhibit the full and rapid commercialisation of additive manufacturing in the UK.

Over the last three years, AM UK has undertaken a series of consultations and pulled together the working group outputs to understand what industry needs to adopt and capitalise on the technology and to understand the future potential, as established by the

research community. We believe that this combination of proactive, extensive consultation, along with active, senior, cross-industry support and representation from academia and government has enabled AM UK to develop a strategy which accurately represents the UK priorities and opportunities.

In September 2016 the steering group published a further report - 'Leading Additive Manufacturing in the UK: A platform for engagement to enable UK industry to realise the full potential of Additive Manufacturing & 3D printing'. This publication provides a robust framework mechanism for engaging with the UK's additive manufacturing community, to assist the provision of the underpinning knowledge and industrial insights instrumental in forming this strategy.

We believe we are well-placed to gain the necessary acceptance and support for the required investment and implementation activity.



What is additive manufacturing?

Additive Manufacturing (AM), also known as 3D printing, is where objects are created by adding layers of material one on top of another, until a 3D object is complete. The technology has so far been mainly used for rapid prototyping and tooling, but is now

being used to manufacture, repair and replace end-use parts. It is transforming the way some of the UK's best-known companies manufacture their products and has the potential to put the UK at the forefront of global manufacturing.



Digital Process



Enabling new business and new business models

Highly Productive



Enables manufacturing of energy efficient products

Being used in almost all sectors and regions



CASE STUDY

Renishaw

Hydraulic block manifold redesign for additive manufacturing

Additive manufacturing is highly suited for the design and manufacture of manifolds due to its ability to build internal features and passageways.

Renishaw has collaborated with a customer to redesign their current hydraulic block manifold with additive manufacturing in mind. The main goal of the project was to reduce the mass of the component, whilst retaining its robustness.

Due to the increased design freedom associated with additive manufacturing, an opportunity to increase the efficiency of the flow paths was also identified.



Advantages of additive manufacturing

Many companies of all sizes have been quick to spot the potential of additive manufacturing and are already using the technique across their businesses. These include household names such as BAE Systems, Dyson, GE, GKN, GSK, Johnson Matthey, McLaren and Rolls-Royce.

The benefits read like an engineering wish list. By using additive techniques engineers are able to create

objects of great complexity based on highly accurate computer-controlled designs, delivering finished components made from both readily available standard and high performance materials including plastic, metal, composite powders and even human tissue and foodstuffs.

Greater design freedom

It provides greater liberation for designers and allows them to be much more creative. Also, it allows the use of materials considered to be too difficult to form into complex shapes through existing processes, or the use of functionally graded material. Our talented designers are less constrained by many of the practicalities of whether it is possible or economic to actually turn their ideas into reality.

Novel geometries

Additive manufacturing means that many new geometries are now possible. This also means that assemblies of parts can now be made as one piece, which can improve performance and reduce labour costs. There can also be a reduced need for post processing of individual parts.

Decreased cost

There is no need to design and produce costly tooling before starting to make a component. Objects can be fabricated directly from a digital design with the 'printing' or layering controlled by a computer. AM can significantly reduce the cost of production. For example, for the first time manufacturers can create parts without being hamstrung by prohibitively expensive conventional manufacturing methods.

Lead time

In some situations lead times can also be greatly reduced. Large blocks of high performance material, for example some forgings and castings, can have very long delivery times (years in some cases). With additive manufacturing it is possible to use a simple material form, such as wire or powder, to build up a large part. This wire or powder is available with much shorter lead times and often at lower cost.

Reduced waste

By adding layers of material, there can be very little scrap material when compared to traditional 'subtractive' methods of manufacture, such as milling an item from a solid block. In the past, material which had been machined away would be recycled at a much lower value. Additive manufacturing techniques have the potential to significantly reduce wastage of precious high value materials.

Personalisation/customisation

We're now living in a society where customers and consumers increasingly expect a high degree of personalisation, with bespoke products delivered next day which meet their needs exactly. Think ordering a personalised mobile phone cover online for a low fixed price with free next day delivery. Additive manufacturing makes it possible to produce one-off items or small batch sizes at a reasonable cost and allows a high degree of customisation, even in serial production.

Sectors

Additive manufacturing does and will impact a range of businesses; from aerospace to jewellery and from medical supplies to construction. It is a cross-sectoral technology that can be disruptive, transformational, and competitively sustaining. Its various functional advantages provide different benefits to different sectors. As such, its uptake across and within sectors will rapidly accumulate as its functional capabilities improve. As the various additive manufacturing technologies improve they will be deployed in many novel applications.

Additive manufacturing is set to revolutionise many businesses globally by providing a radically new method of production that enables new, functionally superior designs to be realised at lower cost with enhanced function, productivity and greater sustainability.



Supply chains and business models



Additive manufacturing will transform supply chains and the way businesses compete by introducing revolutionary new business models which take advantage of the technology. The disruptive aspect of additive manufacturing means that smaller, innovative, agile SMEs have a key opportunity to compete and take market share-given the right support-leading to future supply chain growth. Larger suppliers in sectors already engaged could significantly increase their industrial presence in the UK by taking on the additive manufacturing opportunity; and those in other sectors will be presented with growth opportunities through future waves of additive manufacturing adoption. Supporting professional services businesses; finance, legal and training, will grow to support the needs of in- country demand, with corresponding global export opportunities.

Digitised Manufacturing

Many noted benefits of additive manufacturing are only possible by taking advantage of the fully digitally enabled nature of the technologies. The Industrial Digitisation Review, which encompasses digital technologies, recognises additive manufacturing as one of its main physical manifestations. Its digitally-enabled characteristics means additive manufacturing represents a step change in the flexibility of production. It allows businesses to design and make better products, replace parts that are no longer in production, modify existing parts for improved performance, enter new markets and develop new business models, react more quickly to changing demands, and explore the possibilities of digital manufacturing.



Business Case

There is a compelling case for UK companies to exploit additive manufacturing. It will enable industry to deliver world-beating, high value components and systems across a wide range of sectors including machinery and equipment, medical devices, energy systems, aerospace and automotive.

This will upgrade competitiveness, increase productivity and accelerate innovation in the UK. With the right support the technology will lead to significant global export opportunities. We estimate that the UK can

capture over £3.5bn per year (gross value add) of the rapidly growing global market for AM products and services in 2025 with 60,000 jobs, supporting the knowledge economy and generating new highly skilled employment opportunities. This significant market will be made possible by the broad and cross-cutting impact on sectors, supply chains and business models. Its fundamental digital characteristics lend it to being greatly exploited in the future digital economy.

AM versus conventional: for some aircraft structures up to 95% of the high grade aluminium billet is machined away and turned into scrap metal.



Strength of research & industrial exploitation

The UK is well-placed to take advantage of the rapidly expanding market for additive manufacturing, as it has already:

- Become a global force in advanced materials, technology, life sciences and High Value Manufacturing
- An established government and industry-funded National Centre for Additive Manufacturing
- A strong capability in universities, Catapults and R&D organisations
- Recognised leading technological advancements in additive manufacturing.

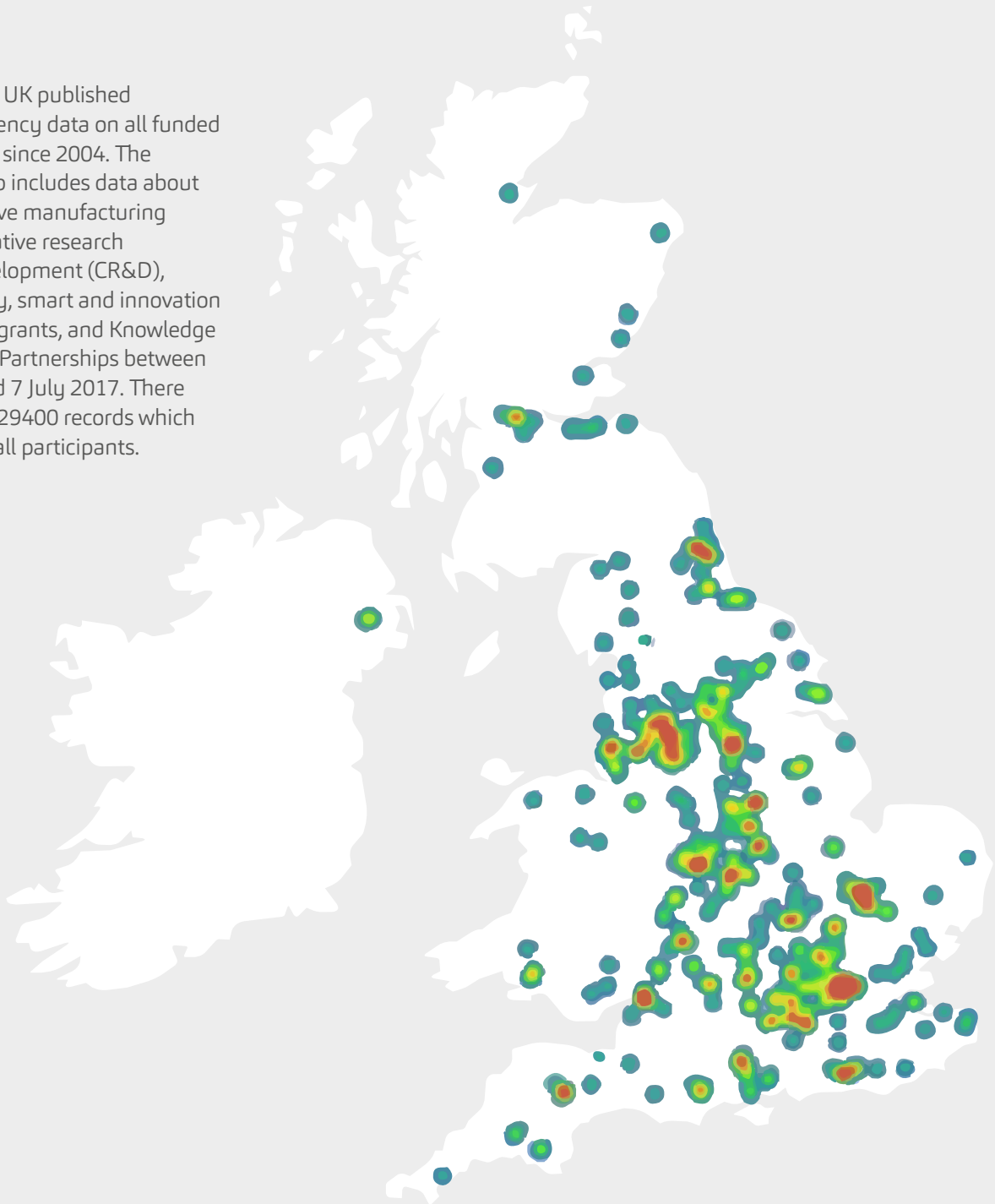
The UK is a world-leading source of additive manufacturing-related knowledge and research

activity. The UK Research Mapping Report (Hague et al.) found that research funding doubled from £15 million committed in 2012, to £30 million in 2014 and the number of organisations involved has also doubled to around 250, with most of this growth coming from greater engagement with commercial partners. Since 2012 The UK's EPSRC and Innovate UK's combined investment in additive manufacturing R&D, including capital grants, has been well over £200 million.

With the commercialisation of additive manufacturing, businesses large and small, up and down the supply chain stand to gain. Supporting professional services businesses such as finance, legal, and training companies are also set to benefit.

Geographical distribution of industrial activity and academic research

Innovate UK published transparency data on all funded activities since 2004. The heat map includes data about all additive manufacturing collaborative research and development (CR&D), feasibility, smart and innovation voucher grants, and Knowledge Transfer Partnerships between 2004 and 7 July 2017. There are over 29400 records which identify all participants.

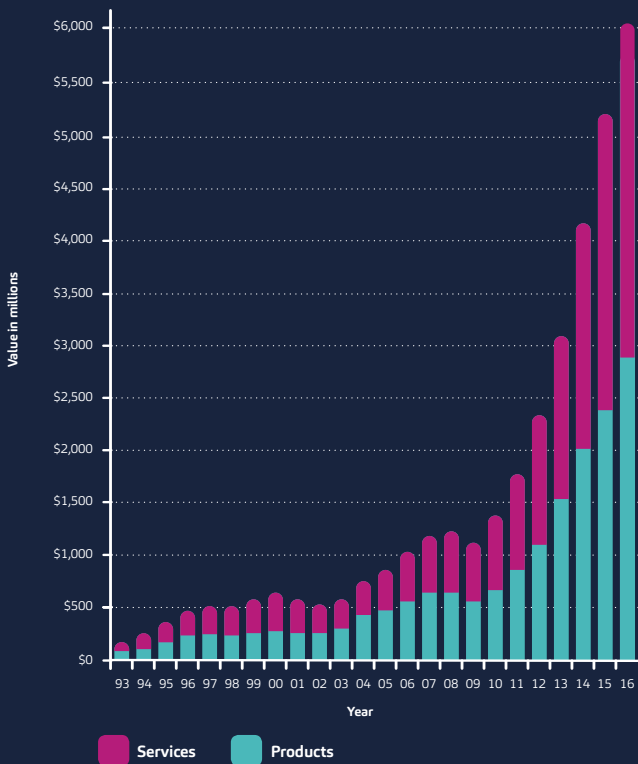
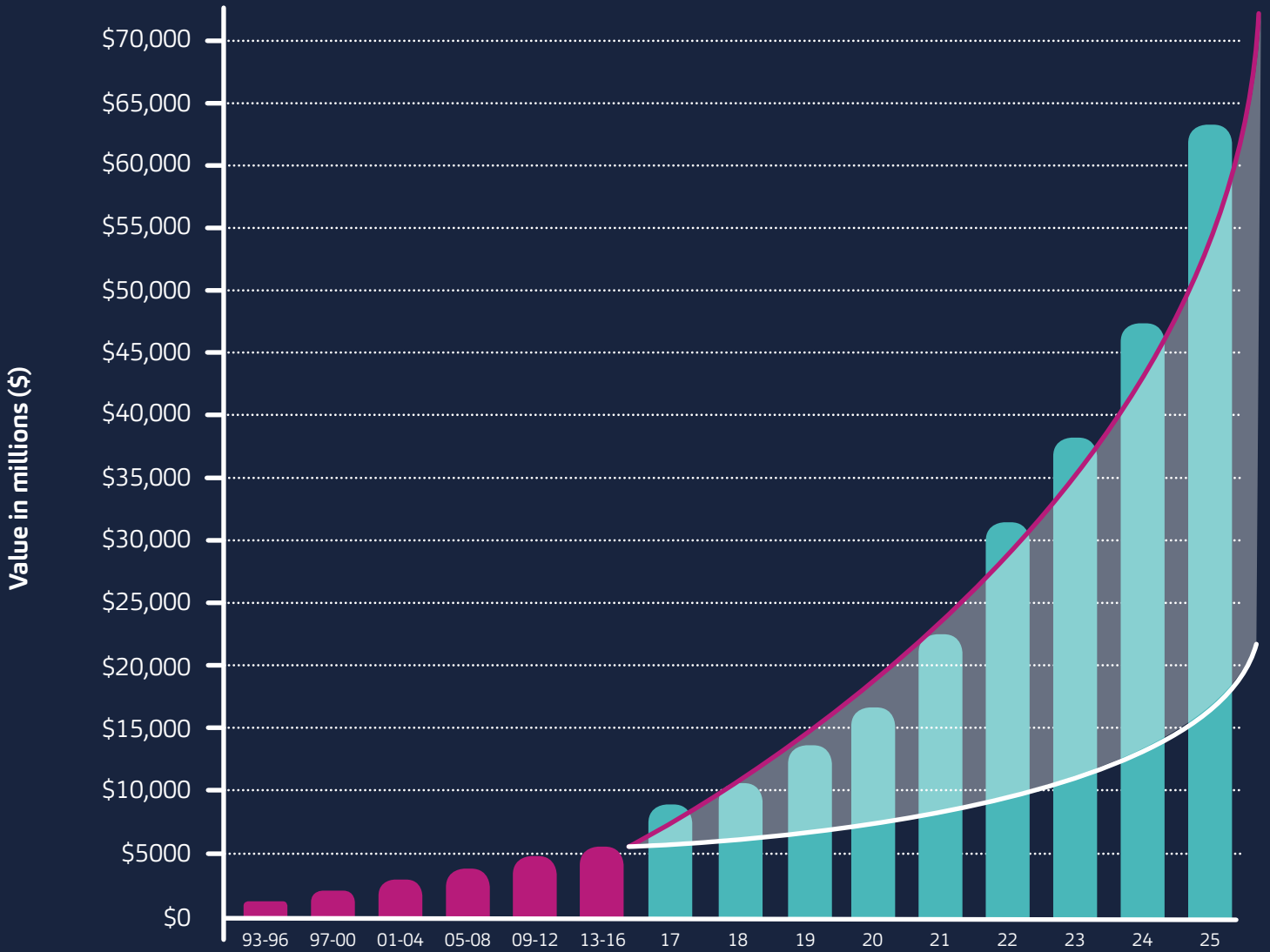


Notes

1. The postcodes used to plot location are where the company is headquartered, therefore there is a slight London-centric bias due to a number of companies being headquartered in London, while the actual activity is more dispersed around the UK.
2. This data is only for InnovateUK-funded activity and does not reflect non-funded activity locations

Image courtesy of AMRC

Global opportunity



Year

- Upper Boundary Market Forecast
- Lower Boundary Market Forecast

The cumulative annual growth rate of additive manufacturing's value is forecast to remain at >20% levels for many years to come.

Source: Wohlers Report 2017



This page and front cover: Detail from an Annular Radial Flow Recuperator for a Microgas Turbine System developed as part of the Innovate UK supported SLAMMIT project in collaboration with Delta Motorsport Ltd

‘Component designed and manufactured by HiETA Technologies Ltd on a Renishaw AM system

Global competition

A selection of funded initiatives around the globe with additive manufacture at their centre



For more details regarding a number of these initiatives please refer to Appendix 1.



• **Switzerland/Sweden**
Swiss-Swedish Innovation Initiative

• **Russia**
National Technology Initiative

• **Italy**
Association of Italian Additive Technologies

• **South Korea**
Manufacturing R&D Mid- to Long- term Roadmap

• **China**
Made in China 2025

• **Singapore**
National Additive Manufacturing Cluster

• **India**
Make in India

• **Australia**
Advanced Manufacturing Fund

• **South Africa**
The Rapid Product Development Association

The Strategy

A well-implemented strategy for additive manufacturing will enable UK industry to exploit the technology faster and more effectively than our overseas competitors. A carefully targeted approach will protect and advance High Value Manufacturing activities across all sectors, as short time to market, increased mass customisation, open source product development and step change improvements in the overall operational effectiveness of manufacturing become critical for success.

For this reason we recognise the importance of addressing the High Value Manufacturing sectors. Manufacturing in the UK today employs 2.6m people and earns £168bn GVA for the national economy. High Value Manufacturing represents approximately 60% of this. It is also central to the activities of world-beating UK-based companies and brands across the automotive, aerospace, medical technology and pharmaceutical sectors.

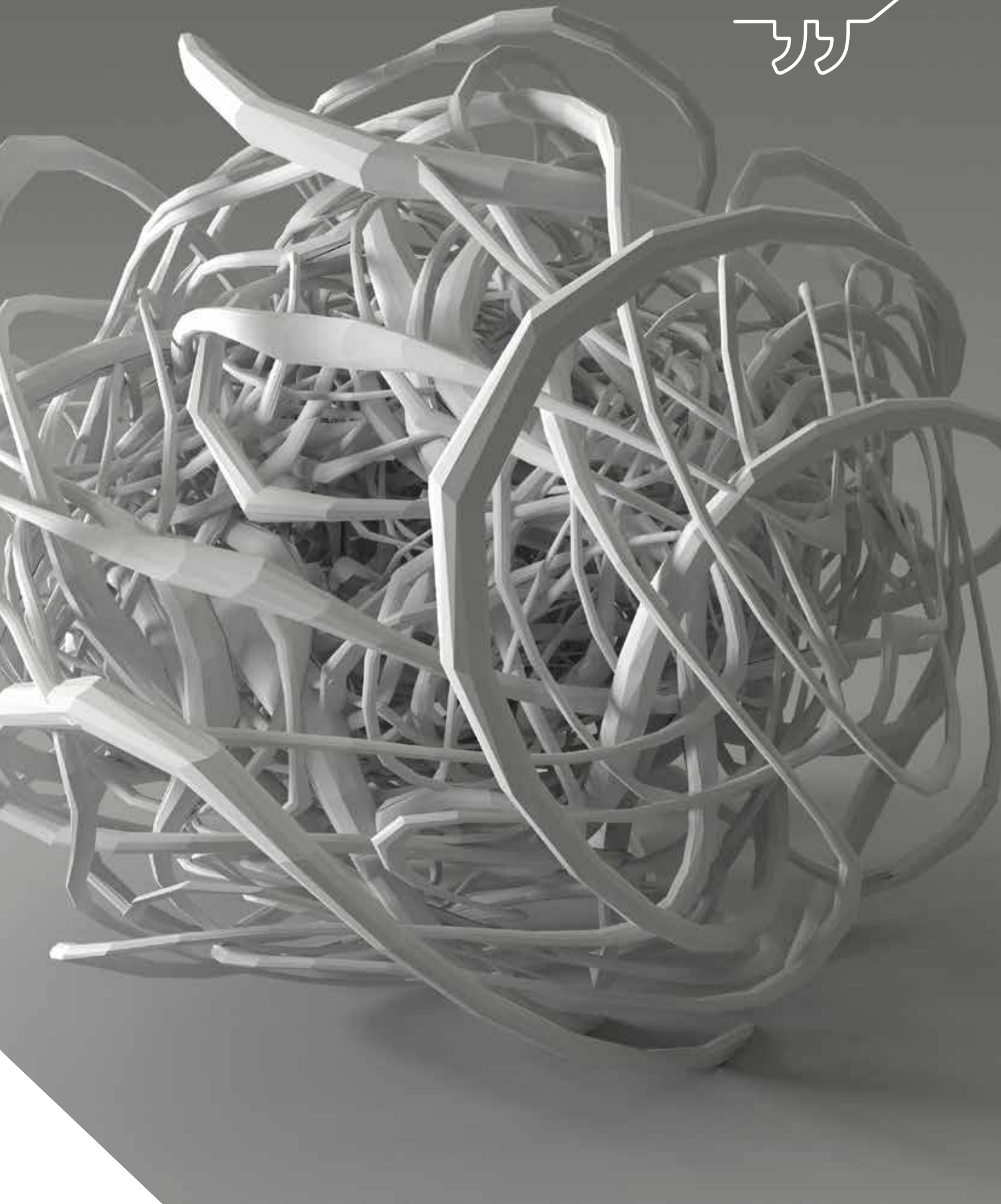
The UK has some distinct and potentially game-changing additive manufacturing material and machine supply technology companies and innovators.

Delivering this additive manufacturing strategy is a key part of the overall High Value Manufacturing strategy for the UK, which underpins existing business growth plans and opens up new markets and future growth in the medium and long term.

The alternative is to do nothing. We firmly believe that inaction will lead to a steady decline in High Value Manufacturing overall and that this would have a major negative impact on the economy and employment.

The strategy has been developed fully mindful of the part additive manufacturing plays in the pervading move to industrial digitalisation and forms a collaborative part of realising this key technology to deliver tangible commercial benefits to the UK.

This strategy takes the technology beyond rapid prototyping and tooling, to enable UK industry to realise its full potential for direct production.



Challenges

Much has been done by industry, government, and academia to advance the UK's industrial additive manufacturing capabilities. However, several challenges and barriers are preventing or slowing further development and exploitation of the technology. These were outlined in the AM UK publication 'A Platform for Engagement' in September 2016, and are repeated below:

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



Recommendations

The consultation process undertaken to date has identified a number of barriers. Recommendations to overcome these barriers have been identified by the working groups and are set out below.

In addition, there are two recommendations which resonated across all of the working groups.

These are:

1. The need for a strong and collaborative campaign to raise awareness among all firms in all sectors to as the reality and potential of additive manufacturing, as well as to dispel the myths and hype that surround additive manufacturing technologies
2. The ongoing adoption of additive manufacturing in UK industry is fundamentally linked to industrial digitalisation. As such, we strongly commend the tighter operational linkages being developed between the additive manufacturing and industrial digitalisation funding and policy groups

Design

The fundamental step-change driver for a move to additive manufacturing is the design opportunity presented. The design group focused on supporting effective design of additive manufacturing parts; designers requiring resources to help them leverage additive manufacturing technology, the resolution of fragmented CAD workflows and undeveloped tools not necessarily optimised for the creation of advanced additive manufacturing geometries.

Generally the need to help businesses furnish designers with additive manufacturing design capability is recognised. Additionally, the use of design thinking to help identify, validate and communicate high-value propositions enabled by additive manufacturing.

Recommendations

- 1 Commission a study to classify additive manufacturing-related design guidelines, best practice and appropriate accreditation to reduce risks for firms seeking to commission additive manufacturing-related design input. Output of study to be made available online as an interactive portal, developed and delivered with the support of professional engineering institutions.
- 2 Run an R&D programme to address gaps in knowledge on design for additive manufacturing, including the development/use of appropriate software and the integration of additive manufacturing design and production.
- 3 Provide support for challenge-led, strategic design activity to identify additive manufacturing opportunities and help firms in developing new additive manufacturing value propositions.

Materials and Processes

As outlined in the group's 2016 publication, 'A platform for engagement to enable UK industry to realise the full potential of additive manufacturing and 3D printing', the range of materials and processes covered by the term 'additive manufacturing' is broad. Encompassing this remit of processes and materials, the group covered the equipment options available now and for the future, materials properties and supply, the range of processing parameters, research around knowledge gaps and innovation opportunities.

Notably, additive manufacturing post-processing presents challenges which are different to those from conventionally processed material, as well as issues regarding the complex, functionally improving design potential. Supply chain

future capacities are largely unknown and hence are not understood and will likely hamper additive manufacturing uptake, with sector specific challenges being recognised. These will include additive manufacturing process selection and scale-up (size and productivity), automation, process feedback and control, digital manufacturing approaches amongst other areas.

Recommendations

- 1 Collation and publication of case studies of best practice in additive manufacturing adoption across all sectors and firm sizes, covering all relevant technical and commercial issues.
- 2 Fund R&D activity around the creation of online tools to help educate potential users in areas such as material supply and process selection. For example, drawing upon the experience of successful additive manufacturing adopters.
- 3 Support R&D and other programmes to develop equipment capability with a view to increasing productivity, process stability and other areas. Drawing upon a UK AM supply mapping exercise, the programme would also cover other value chain elements such as finish machining and materials supply.
- 4 Support R&D and other programmes to develop knowledge of how manufacturing should be optimised, including post-processing.
- 5 Continue and increase funding into the development of new materials designed for additive manufacturing - recognised as a significant opportunity for the UK.

Inspection, Test and Standards

The technology of additive manufacturing will bring an entirely different way of manufacturing items, but it still has an association with the fundamental methods and standards of testing, interoperability and specifications, which have supported the 'traditional' manufacturing sector for many years.

The groups considered the standards, inspection, certification and regulations requirements within additive manufacturing and 3DP, noting the dependence on a variety of factors including, but not limited to; industry sector, safety criticality, the working environment, compatibility, the process used and material considerations.

The range of additive manufacturing technologies, different materials and different combinations of processing steps which can be used with each technology underline the importance of identifying each step in the production process and the required relevant standards.

Additive manufacturing equipment demands new robust and validated in-process feedback systems necessitating active research into potential techniques. Final part measurement using the latest technologies are not standardised and are typically slow with a lack of best-known practices and traceability.

Recommendations

- 1 Implement a co-ordinated and ongoing additive manufacturing standards development and communication initiative – with industry working in collaboration with relevant standards-setting organisations – to support industrial adoption in the short, medium and long term for current and emerging additive manufacturing technologies.
 - 2 Develop and share Non-Destructive Testing (NDT) and mechanical testing processes suitable for additive manufacturing to enable 'fit for purpose' evaluation for generic and sector-specific needs. This would include all relevant technical elements and accessible material property data.
 - 3 Develop and maintain an accessible additive manufacturing material properties and standards database, for current and emerging additive manufacturing technologies.
-

Commercial, Intellectual Property and Data Management

There is a strong appetite to fund additive manufacturing equipment amongst key lenders. The group identified the need for quick/easy wins in order to generate greater momentum for additive manufacturing within the commercial community. Opportunities exist to develop more bespoke and therefore more affordable funding options. As many of the barriers to greater investment are not additive manufacturing specific; for example Brexit, skills shortages and leadership challenges, these were reviewed particularly in respect of the technological advancements presented by additive manufacturing.

Consideration was made of the limited knowledge and capability regarding additive manufacturing within the commercial community. Specifically a lack of confidence

in an understanding of the additive manufacturing equipment aftermarket infrastructure.

The IP and Security group reviewed the need for enhanced security across networks, files, processing and cloud providers, noting this is required for all digital manufacturing activity. The call for action regarding security issues-notably cyber security-is an industry-wide issue. Regarding IP, additive manufacturing is particularly vulnerable as whole product specifications can be accessed. Design skills, product standards compliance and quality are core UK attributes. Therefore, to protect our reputation for quality and reap the financial benefits of our designs the integrity of production needs to be embedded in the integrity of the digital asset.

Recommendations

- 1 Run co-ordinated exercises to identify additive manufacturing-specific and digital manufacturing-related IP issues (including licencing, payment methods, design and collaboration). Set out a collaborative work programme to address the issues identified, highlighting roles and responsibilities.
- 2 Implement an additive manufacturing-related product liability definition and collaborative action programme.
- 3 Commission and publish case studies of the economics of additive manufacturing and different additive manufacturing-related business models, to provide evidence to help the finance community make investments to enable firms of all sizes to adopt additive manufacturing. This aims to make additive manufacturing with better understood in the financial community, resulting in more funding for adoption of additive manufacturing by business.

Skills and Education

As a theme absolutely core to the growth of this future critical manufacturing technology, the group considered the broad remit of what additive manufacturing skills are; and what education and training of additive manufacturing is required to deliver its benefits. This included standards - new, updated, or existing - for any relevant education and the consideration of additive manufacturing as a subset of many disciplines; fundamental, or core additive manufacturing aspects; those linked to additive manufacturing and those pertaining to broader digital manufacturing.

Delivery mechanisms were reviewed, recognising the slow approval process for new higher education courses. The

group looked to capture the additive manufacturing skills needs of industry and also the need to build awareness and knowledge across the whole educational sector, with specific support for teachers, trainers and lecturers. An important element observed was the need to manage differences in additive manufacturing awareness and skills of new recruits with experienced employees. The group acknowledged there is not yet a compelling commercial case for additive manufacturing training (as it requires volume), so various options were developed.

Recommendations

- 1 Develop skills packages for short, medium and long-term and design appropriate delivery mechanisms for the current and future workforce, including apprenticeships and vocational training. Provide public funding to pump-prime programmes to be taken forward by industry.
 - 2 Expand on existing KTN additive manufacturing Special Interest Group activity to continue to build and connect the additive manufacturing industrial community to support development of an additive manufacturing capable workforce across UK industry.
 - 3 Create and run an additive manufacturing awareness campaign to help firms of all sizes and sectors accelerate industrial exploitation in the short, medium and long-term.
-

Supply Chain Development

There was no specific working group covering this theme. However, many of the recommendations developed within the working groups encompassed elements of the supply chain and a number of specific recommendations have been collated as a result.

Recommendations

- 1** Produce a comprehensive map of the UK additive manufacturing supply chain capability and capacity to be produced. Determine gaps and UK strategic priorities. Fund a programme of various activities to address the strategic weaknesses.
 - 2** Commission and maintain an online map of UK additive manufacturing supply-chain capability and capacity. Determine gaps and fund a programme to address strategic weaknesses.
 - 3** Drawing upon a UK additive manufacturing supply chain mapping exercise, the programme would also cover other value chain elements such as finish machining and materials supply.
 - 4** Extend the Catapult 'Reach' programme targeting SMEs.
-

Implementation

The collaborative activity of the working groups was facilitated by the Steering Group and this included development of desired activity roadmaps and implementation scenarios. Part of this work created a SWOT analysis, (Appendix 2) as well as a set of cross-cutting recommendations around the implementation of an additive manufacturing strategy.

Recommendations

- 1 Develop links to all aspects of the digital space, connecting with relevant supply chain review activity and follow through any recommendations in both the digital and real world.
 - 2 Clarify digital manufacturing-related licencing, payment methods, design, and collaboration. Set out a collaborative work programme to action issues.
 - 3 Implement Phase 2 investment in the National Centre for Additive Manufacturing , developing it through a hub and spoke model.
 - 4 Support the development of an expert UK additive manufacturing User Group, similar to the successful USA model.
 - 5 Establish and run a national help and contact point organisation.
-

CASE STUDY

GKN Aerospace

GKN Aerospace identified as early as 2012 that additive manufacturing was an area of technology that could massively affect the design and manufacture of components in the aerospace arena, despite its then relative immaturity. To stay competitive, GKN needed a detailed understanding, as well as manufacturing capability.

The AM spectrum is broad, so a down selection of the potential technologies was made, to align to its current portfolio of products – hence Electron Beam Melting (EBM) of titanium powder was initially examined.

Investment was made at Filton with the support of the Aerospace Technology Institute (ATI) and GKN investment, initially through the EcoHVP Program, but latterly others as well, in equipment and technologies targeting thick wall (>5-10 mm) structural aerospace components.

Customer requirements have driven the need to investigate thinner structural assemblies. The first production contracts awarded to GKN were for thin wall components that exploited AM's ability to integrate smaller sub-assemblies into larger units with minimal post-build treatment or machining. These are routinely manufactured and certified for flight.

Further development at Filton has seen the creation of Selective Laser Melting (SLM) capability, targeting both structural airframe, as well as higher temperature engine components.



Implementing the UK Additive Manufacturing Strategy

This is the first National Strategy for additive manufacturing in the UK. Similar activities in competing countries (e.g. USA, Korea, etc.) have demonstrated immediate and tangible benefits. The strategy will bring together all the key stakeholders and provide the critical mass necessary to focus efforts and build a national competency in the use of additive manufacturing. It will also ensure a strong and relevant pipeline of research and innovation activities to sustain future competitiveness of early adopters and those taking up the technology in years to come.

Without the implementation of this strategy the UK will fall behind in the global race to exploit additive manufacturing and will be unlikely to catch up later. The rapidly increasing maturity of additive manufacturing technology and its recently proven capability to become a more mainstream production technology means that now is the optimal time for the UK to make the strategic investment for industrial scale-up and adoption.

The benefits to the UK economy of correctly developing and adopting additive manufacturing as a production technology are so compelling and significant that we need to agree a nationwide approach, to ensure that the combined efforts of industry, academia and government are focused on co-ordinated, prioritised activities. These must build on our strengths in research and innovation and address the critical barriers to successful commercialisation, whilst supporting businesses across

all industry sectors to develop the necessary skills and expertise to take full advantage of this game-changing technology. Our challenge is to implement the National Strategy as soon as possible. A first step is to develop a wider national consensus on the UK strategy presented here in the context of the developing UK Industrial Strategy, as a basis to then implement a delivery plan with appropriate levels of investment and support from government and industry working together.

It is recognised there is no national co-ordination or point of contact for additive manufacturing in the UK; and research and innovation activities are generally academic and single-sector industry-based. This makes it difficult for companies to get any information or support about additive manufacturing and brings with it the limitation that problems and solutions are being worked on in isolation, with only small, local pockets of expertise developing. Existing centres, for example the National Centre for Additive Manufacturing, EPSRC hubs and the HVM Catapult centres go some way towards solving these issues, but are focused on specific research and innovation agendas and remain relatively isolated and hard to access for industry in general. Therefore, a single national co-ordination or point of contact for additive manufacturing in the UK is a vital part of implementing the strategy.

FORTUS 400mc

FORTUS
3D PRODUCTION

EUROPEAN UNION
European Regional
Development Fund 2007-13

Control panel with a digital display and a keypad. The keypad includes buttons for 'METAL', 'LAYER', 'PAUSE', 'HEAT', and 'START', along with a numeric keypad and function keys like 'STOP' and 'RESET'.



Strength of research & industrial Exploitation

To address the recommendations made, AM UK has identified a five-year requirement for public investment of £225m to magnify and reinforce the industrial private venture and other investments being made and proposed. The range of major activities will require government support and commitment from a number of areas including business, skills, and regions.

As mentioned earlier, the additive manufacturing research funding has generated a significant increase in engagement within commercial organisations. In consultation with High Value Manufacturing industries, the steering group has recently identified that the planned level of investment by UK industry in additive manufacturing is £600m over the next five years, with a potential additional £400m if government funding becomes available. General machinery, aerospace and advanced materials companies are the main investors, with other sectors still developing their plans.

The UK Government's 2017 Green Paper 'Building our Industrial Strategy' provides a pathway to future funding. Additive manufacturing is relevant to a number of the pillars identified within the paper. A new fund, the Industrial Strategy Challenge Fund (ISCF), has been established to support business-led collaborations to focus on the challenges, opportunities and technologies that have the potential to transform industry. A number of the recommendations presented in this strategy are directly relevant to this fund and will be bid accordingly.

However, a significant portion of the essential recommendations are considered to be outside the remit of the fund and will need to be addressed to deliver the impacts outlined.

Also referenced within the Green Paper is the industrial digitalisation sector deal, led by Juergen Maier. Additive manufacturing is clearly intrinsically linked to digitalisation and the ongoing review recognises that using additive manufacturing as a core case study for this deal. This reflects positively on the recommendations made regarding links with the digital space.

The delivery network and timing

In addition to funding, the delivery of this challenging strategy will be achieved by drawing upon the UK's strengths in its existing network of industry, RTOs, leading universities, consulting companies, financial institutions, trade associations, and professional organisations. These are widely dispersed geographically and so can work with Local Enterprise Partnerships (LEPs) where necessary to ensure maximum exploitation.

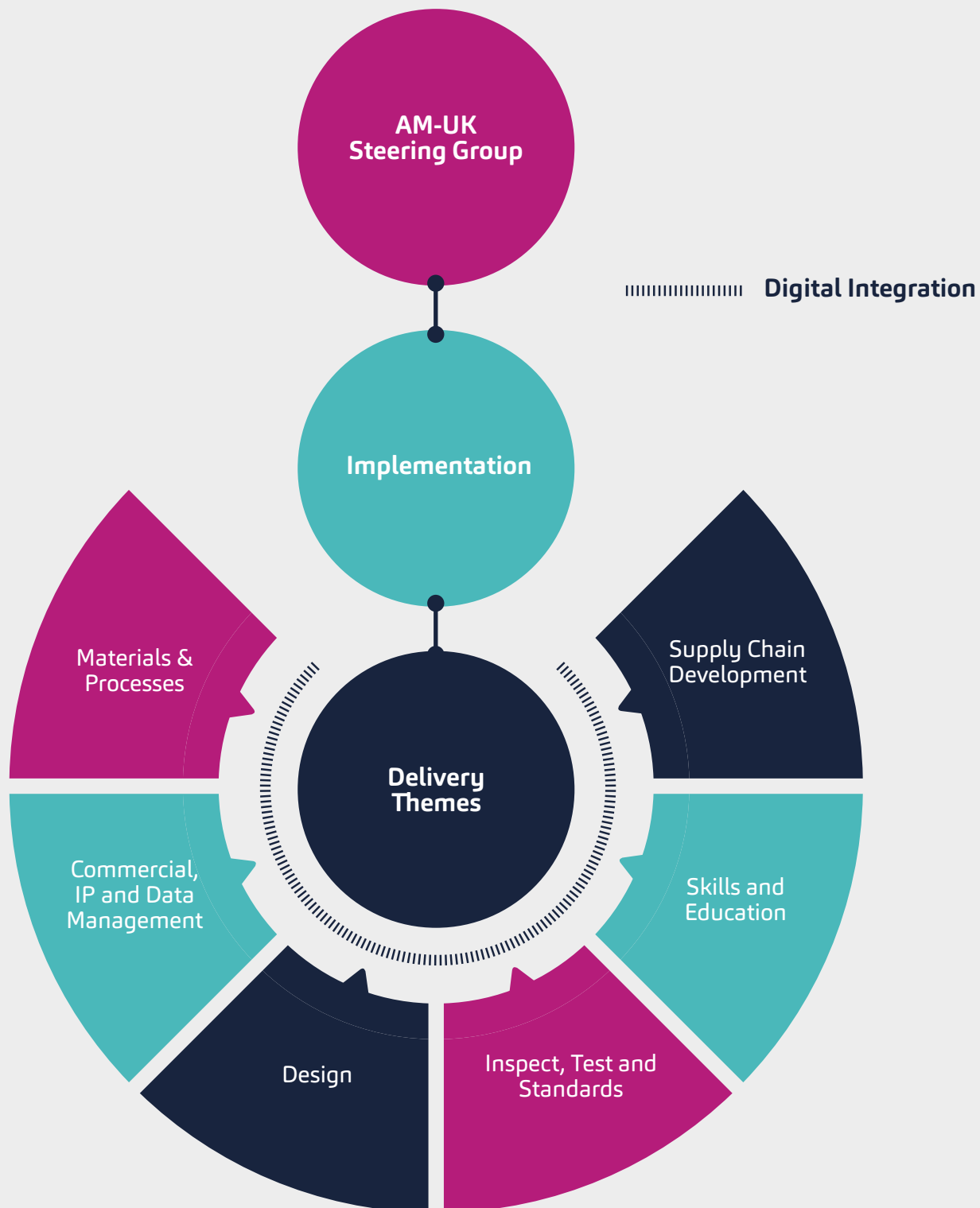
The recognised delivery authorities required to respond to these recommendations are Innovate UK, the KTN additive manufacturing Special Interest Group, High Value Manufacturing Catapult and RCUK.

The public investment programme needs to de-risk adoption and scale-up for companies. It will engage with them and encourage private finance investment according to the following positioning:

- Companies who already know about additive manufacturing and may have already invested
- Those who don't but need to know, about additive manufacturing – a key target for this UK investment
- Filtering out the companies who won't or can't make the necessary investment

The timing is now – the additive manufacturing Steering Group, which includes key industry stakeholders, is fully engaged. Additive manufacturing has been a very active research and innovation area in recent years with a large number of funded projects across a range of funders such as EPSRC, Innovate UK and Horizon 2020. There are a small number of sector-focused projects ongoing and due to start imminently, with content and deliverables well-aligned to meeting some elements of the challenge identified in this strategy. Previous funding competitions in additive manufacturing have consistently been heavily over-subscribed, demonstrating that industry has both the need and the capacity for substantial further investment.

With the delivery of this strategy and the development of the wider national consensus on the need and proposed actions, the emphasis will switch to expanding the implementation activities and determining the monitoring and updating process. All organisations with the private and public sectors are encouraged to get involved in this implementation.



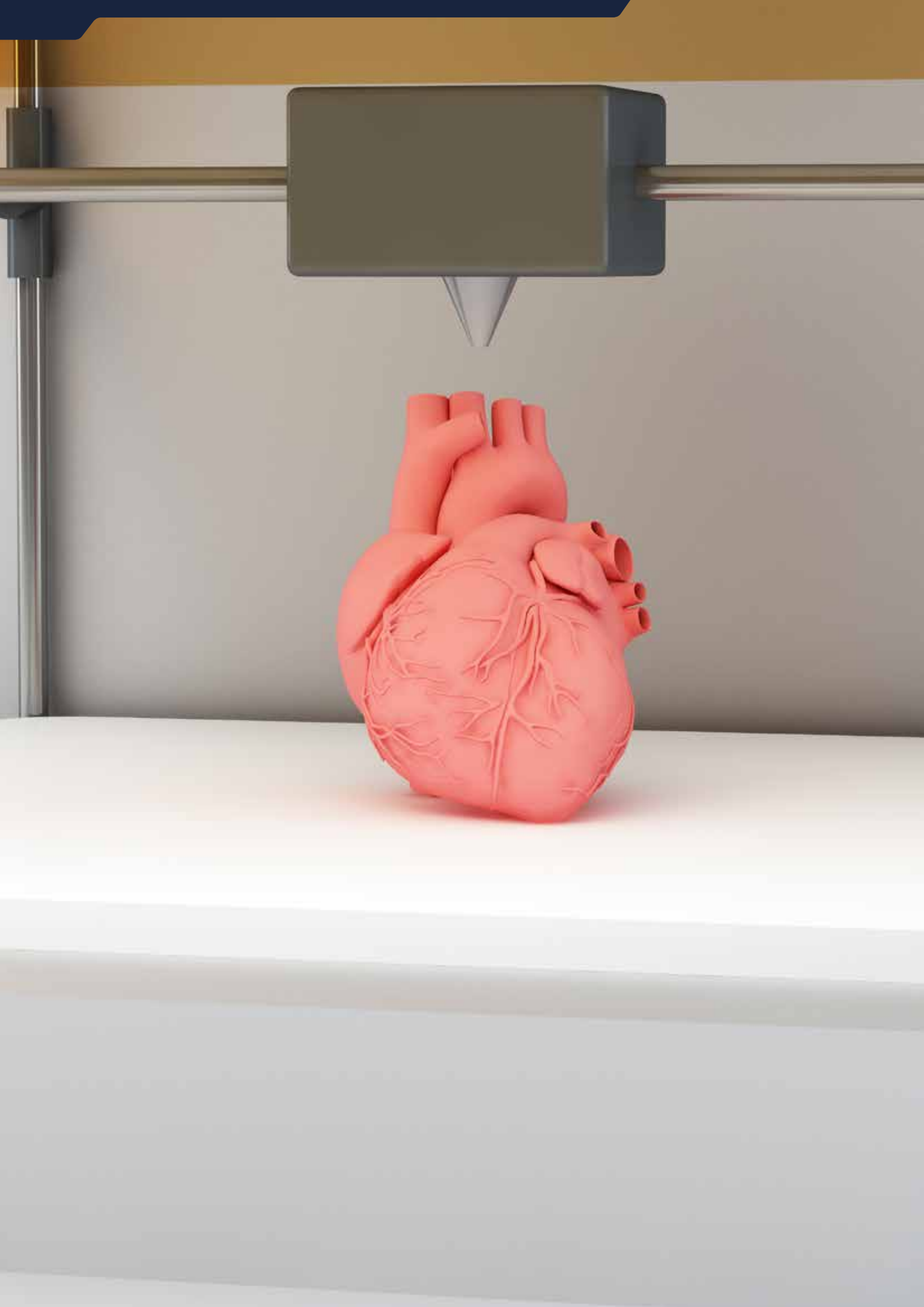
A call to action

A properly funded and governed strategy is a critical success factor for realising and protecting the anticipated benefits of additive manufacturing. Hesitation in providing the necessary UK direction and funding is likely to result in:

- Additive manufacturing being seen largely as just another possible manufacturing technique
- Pockets of excellence within larger organisations, but little extended supply chain benefits
- Increasing commoditisation of certain SME activities
- Little best practice sharing to ensure sustainable business case realisation
- Lowest cost offshoring of key elements of production processes

An effective UK Government-endorsed additive manufacturing strategy will:

- Be underpinned by a clear implementation framework and plan
- Form an integral part of the UK's Industrial Strategy, closely linked to the need to support industrial digitalisation
- Be led by industry, but subject to agreed and measurable governance
- Exploit existing centres of excellence business case realisation
- Focus on targeting the identified barriers to entry, but do so in areas that bring a better chance of long term sustainability
- Seek to develop areas that will bring knock-on benefits for the wider UK economy e.g. Medical sector to help reduce costs of healthcare provision; Energy sector to improve efficiency of energy production
- Stimulate an environment for developing and retaining additive manufacturing-related skills in UK business case realisation
- Recognise there is probably a two-year window of opportunity to act



Appendix 1

Country	Recent AM-3DP Strategies/ Policy Reports	Example-AM-3DP areas of focus/initiatives
China	<p>AM highlighted as part of “Made in China 2025”: Nine priority areas: improving manufacturing innovation, integrating IT and industry, strengthening the industrial base, fostering Chinese brands, enforcing green manufacturing, promoting breakthroughs in 10 key sectors, advancing restructuring of the manufacturing sector, promoting service-oriented manufacturing and manufacturing-related service industries, and internationalising manufacturing. ¹Has also produced “Additive Manufacturing Industry Promotion Plan 2015-2016”</p>	<p>Five explicit areas of focus for AM in China: development of AM materials (metal, non-metal, medical-specific); improvement of processes (for metals/non-metals: SLM, LENS, EBSM, EBDM, SLA, FDM, SLS, et al.); development of equipment; establishment/refinement standards; promotion of demonstration projects. Particular focus on aerospace and medical applications.</p>
Germany	<p>AM has dedicated chapter within “German Bundestag: Report on research, innovation and technological performance Germany 2015” ² : Within broad context of high-technology manufacturing, strong connection between growth of Industry 4.0 and AM – perceived an area of strength and opportunity for Germany.</p>	<p>Leverage links between Industry 4.0 and AM to be promoted (via Ministry and Economy and Energy); government should support development of QA and testing/certification activities; regional programmes to support collaboration with research institutes (via Ministry for Education and Research) and coordination of currently fragmented AM support programmes; need to ensure AM skills development in universities, schools and in-company – requirement for AM competence for teachers/trainers.</p>
Japan	<p>AM highlighted within “2014 Points of Economic and Industrial Policies” ³ as key to ambition to achieve transformation of Japanese manufacturing industry and the revitalisation of regional manufacturing activities.</p>	<p>Particular focus on role of AM in revitalisation of regional clusters through development and deployment of AM technologies. Broader aim of transformation of Japan’s manufacturing industries to be high-value added ones by developing next-generation 3D printers and materials for industrial use, speeding up the printing process (10x), making it more precise (5x), and achieving greater diversity in materials, as well as peripheral technology including infrastructure for evaluating internal and external 3D measurement</p>

Global competition

Country	Recent AM-3DP Strategies/ Policy Reports	Example-AM-3DP areas of focus/initiatives
South Korea	<p>AM highlighted within “2015 Smart Manufacturing R&D Mid- to Long-term Roadmap” as one of eight smart manufacturing technologies (smart sensors, cyber physical systems, 3D printing/AM, energy conservation, IoT, cloud computing, big data and holograms). Also produced “2014 Roadmap for 3D Printing Strategic Technology” “and “2014 3D Printing Industry Promotion Strategy”⁵ (and associated new act of government: ‘Act of 3D Industry Promotion’) that covers range of initiatives across a range of government ministries.</p>	<p>The 2015 roadmap targets ‘raising technology maturity by 17% by 2020’ and the necessary technology development will be reflected to the national R&D plan. The 2014 strategy was very broad (e.g. 3D printing education in schools, selecting 10 universities annually to be specialised universities for 3D printing; on-job training for 3D printing, provision of R&D funding for 3D printing and related software, deployment of ‘Mobile factory’ with AM to showcase to SMEs, etc.) but with very specific targets (e.g. to make 5 global leading firms, achieve 15% global market share and 20% of new patents). 2014 3DP roadmap focuses on eight product areas (medicine, die & mold, culture and defense, electricity and electronics, cars, airlines, ship building and energy, and design / distribution).</p>
United States	<p>AM as key strand within National Network for Manufacturing Innovation (NNMI)⁶ (enacted through ‘Revitalize American Manufacturing and Innovation Act of 2014’) under the umbrella of America Makes⁷.</p>	<p>NNMI’s AM flagship initiative is America Makes (along with the associated National Center for Defense Manufacturing and Machining). America Makes is a public-private partnership focused on improving manufacturing competitiveness by: open exchange of AM information and research; development, evaluation, and deployment of AM technologies; supporting supply of education and training in AM technologies; serving as a national institute with regional and national impact on AM capabilities; linking U.S. companies with existing resources, with an emphasis on SMEs and startups.</p>

¹ http://english.gov.cn/policies/latest_releases/2015/05/19/content_281475110703534.htm

² <http://dip21.bundestag.de/dip21/btd/18/043/1804310.pdf>

³ http://www.meti.go.jp/english/aboutmeti/policy/fy2014/pdf/0906_001a.pdf

⁴ <http://english.motie.go.kr/?p=5363>

⁵ <http://www.businesskorea.co.kr/english/news/industry/13270-smart-manufacturing-400-billion-won-invested-smartmanufacturing-rd-next-five>

⁶ <http://manufacturing.gov/nnmi.html>

⁷ <https://americamakes.us/>

Appendix 2

An assessment of additive manufacturing within the High Value Manufacturing sector in the UK, carried out through AM UK

Strengths

- Strong capabilities in value creation and capture from High Value Manufacturing
- Strong research base in AM
- Leading global positions in sectors including pharma, aero, auto, medical, etc.
- Numerous innovative, technology-based SMEs
- Strong design culture, heritage and community
- Culture of innovative and entrepreneurship
- World-leading higher education sector

Weaknesses

- Limited AM-related supply chain capacity
- Limited number of UK equipment/ software companies
- Lack of awareness of potential of AM
- Lack of awareness of practicalities of AM adoption
- Lack of knowledge of AM skills requirements
- Lack of scale in AM skills delivery capacity
- Heavy reliance on non-UK owned Cax vendors
- Limited knowledge of IP-related opportunities for AM
- BREXIT uncertainty w.r.t collaborative opportunities

Opportunities

- Potential for increased value creation and capture from High Value Manufacturing in the UK
- Attract companies to the UK
- Increase productivity
- Increase exports
- Develop and deploy new business models
- Exploit high value niche markets
- Reduce part and tooling costs; and lead times
- Secure existing jobs and create new ones
- Exploit potential of re-distributed manufacturing
- Reduce energy costs and material consumption

Threats

- Weakening of UK High Value Manufacturing capabilities
- Reduced number of manufacturing jobs
- Competing nations making substantial investment in AM capabilities and capacity
- Impact of reduction of part count for sector supply chains
- Potential inability to respond rapidly to address short-term needs and build long-term capabilities and capacity in AM

Appendix 3

Steering Group and Acknowledgements

This work has been led by a Steering Group that comprises:

Paul Unwin	Industrial Chair
Ken Young	MTC (R&D Chair)
Robert Scudamore	TWI (Deputy Chair)
Rob Sharman	Global Head of Additive Manufacturing, GKN Aerospace
Clive Martell	Renishaw
Simon Locke	Dyson
Clare Porter	Department of Business, Energy and Industrial Strategy
Ian Collier	High Value Manufacturing Catapult
Robin Wilson	Innovate UK
Phill Dickens	University of Nottingham
Tim Minshall	Institute for Manufacturing, Cambridge
Charles Featherston	Institute for Manufacturing, Cambridge
David Wimpenny	Manufacturing Technology Centre
James Logan	Manufacturing Technology Centre
Louise Jones	The Knowledge Transfer Network

The thematic workgroup leaders:

Cost/ Investment/ Financing	Richard Hill, Natwest plc,
Design	Ben Griffin, Innovate UK
IP, Protection and Security	Susan Reiblein, Independent
Materials and Processes	Clive Martell, Renishaw plc
Skills/Education	Frank Cooper, Birmingham City University
Standards and Certification	Alex Price, British Standards Institute
Test and validation	Peter Woolliams, National Physical Laboratory

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The Steering Group had assistance from others not mentioned above, this has been greatly appreciated.

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Front cover and image on Page 19: Component designed and manufactured by HiETA Technologies Ltd on a Renishaw AM system.