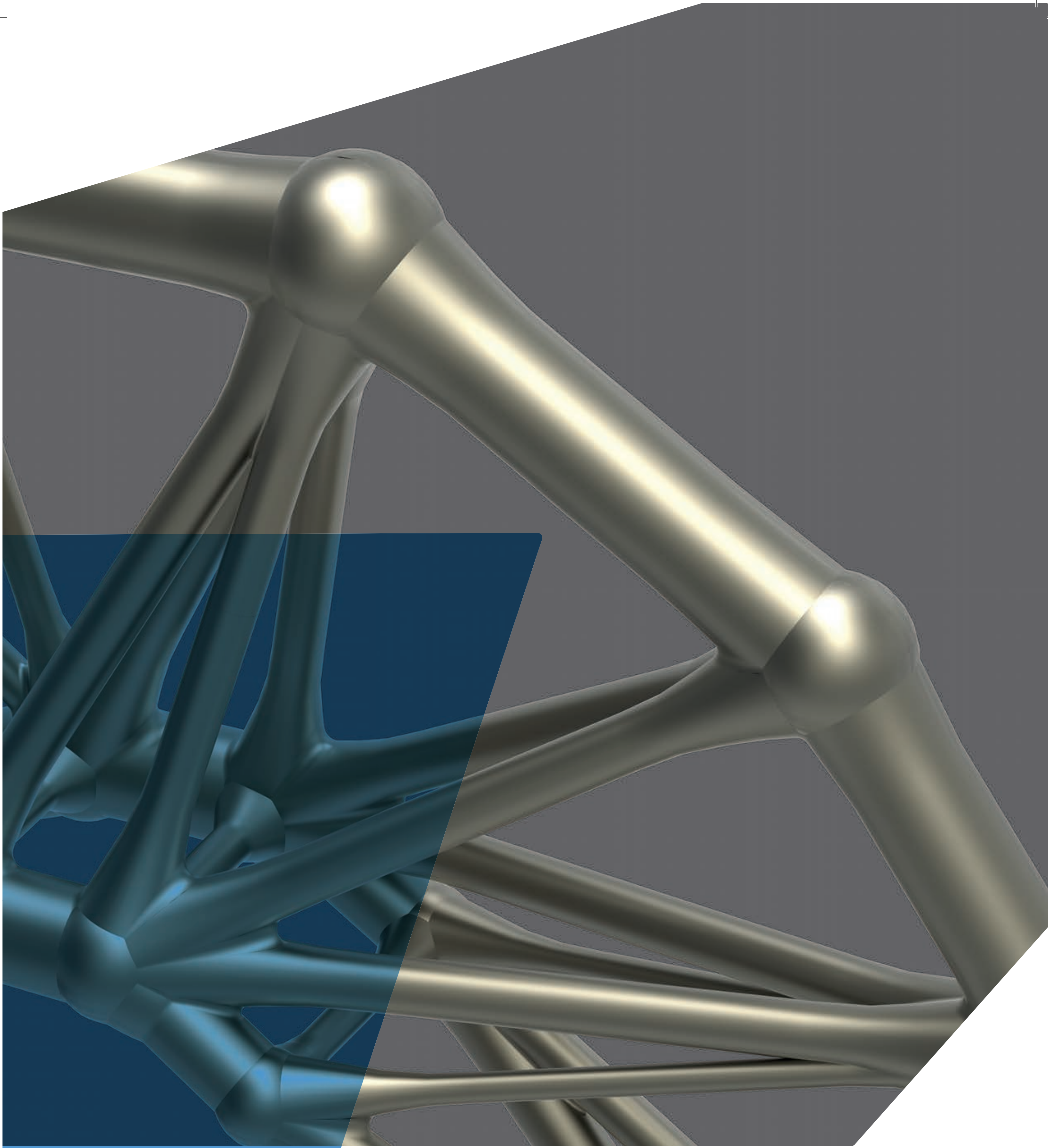

Additive Manufacturing UK

September 2016

Leading Additive Manufacturing in the UK


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Foreword

Neil Mantle
Additive Layer Manufacturing Executive
Rolls-Royce plc

Dick Elsy
Chief Executive Officer
High Value Manufacturing Catapult

High value, advanced manufacturing is one of the UK's strengths. Research, development and adoption of new science and technology combined with a relentless drive for increased operational effectiveness is vital to developing and maintaining world class capability and competitiveness.

Often technologies can be specialised and/or sector specific, but not so with Additive Manufacturing. As a consequence this presents the UK with an opportunity - an opportunity to engage across sectors and develop a national view to maximise the UK benefit from this exciting and globally deployable technology through wider co-ordination and appropriate support.

Industry therefore , from plc to SME, looks forward to continuing to work with the prominent UK AM community, whose work to date is presented in this document and to contribute to a successful and productive UK based Additive Manufacturing Strategy for the UK of high relevance across industrial sectors.

Developing new manufacturing technologies to a position where UK industry can reap the full benefit of their potential is at the core of what the High Value Manufacturing Catapult is here to do.

Additive Manufacturing technologies have enormous potential which, fully realised, will transform product development, supply chains and manufacturing as we know them. Being at the leading edge of the development of this technology will enable UK companies to secure important intellectual property while delivering innovative new products and processes to global markets that will create completely new business models.

Additive Manufacturing is not new but is still too immature to secure wide application in many sectors. By engaging the broadest community, from research through to application, in the development of an Additive Manufacturing Strategy for the UK we will maximise our opportunity to be at the forefront of the exciting developments that are just over the horizon.

I encourage you to engage with the working group and be part of this new era.

Industrial Support

This document has been prepared by the UK Additive Manufacturing Steering Group (see Appendix 1), a set of business, research and leadership personnel with expertise in the domain.

Continuing support from the industrial leaders involved with the April 2015 Positioning Paper: The Case for Additive Manufacturing, is also acknowledged:

Mark Buswell
Head of Advanced Manufacturing Technologies
GlaxoSmithKline Research & Development Limited

Rob Sharman
Global Head of Additive Manufacturing
GKN Aerospace Services Limited

David S Holmes
Director of MAI Manufacturing Function & Investment & Infrastructure Services
BAE Systems (Operations) Limited

Sir David R McMurtry
Chairman and Chief Executive
Renishaw plc

Michael Straughan
Member of the Board, Manufacturing
Bentley Motors Limited

Hamid G Mughal
Director of Global Manufacturing
Rolls-Royce plc

Sir James Dyson
Chairman
Dyson Limited

Sebastian Conran
Director
Sebastian Conran Associates

Mark Elborne
President and CEO
GE UK & Ireland

Paul Howells
R&D Packaging Vice President
Unilever plc

Contents

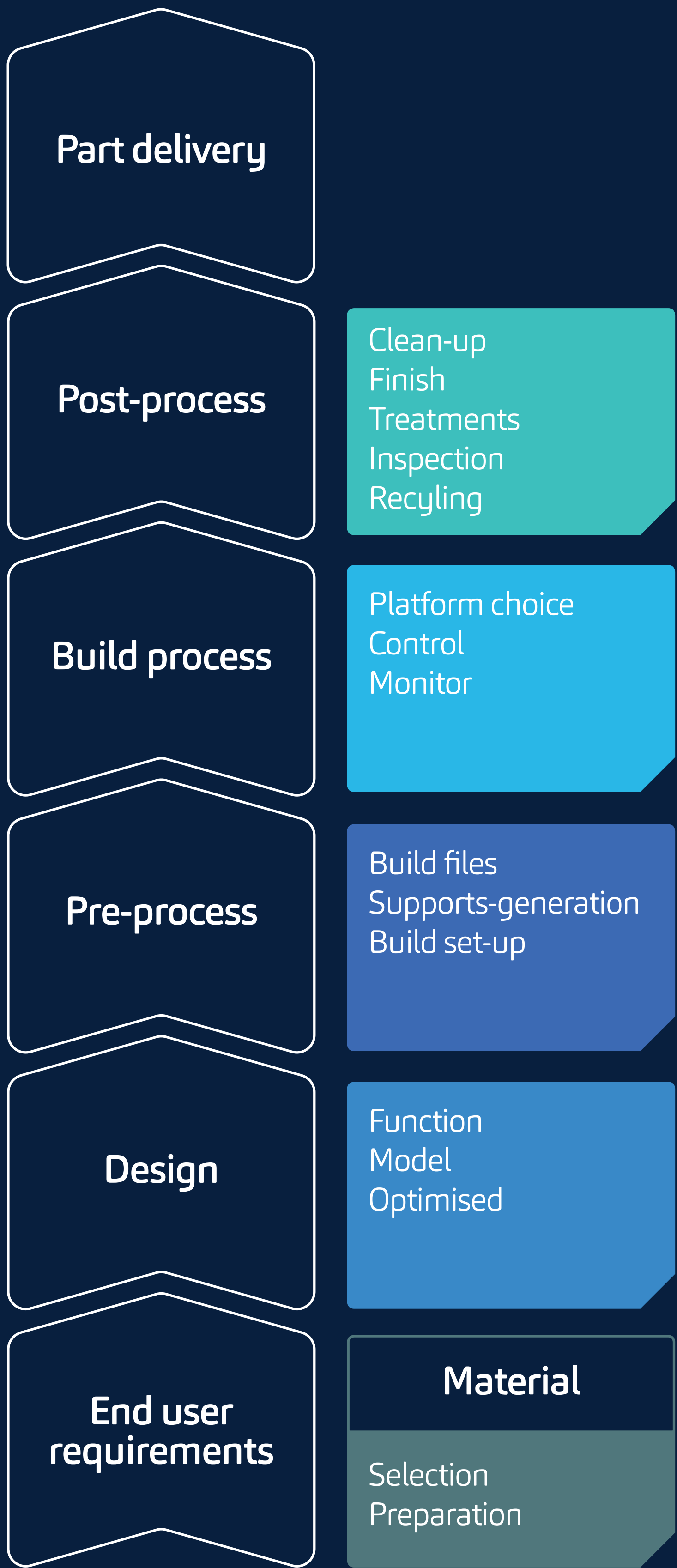
Executive Summary

Additive Manufacturing (AM), also referred to as 3D Printing* is a truly transformational cross-sectoral technology that is having a disruptive impact on design, on manufacturing, on company location and on business models.

It is set to revolutionise businesses globally by providing a radically new method of production, that enables new and better designs to be realised at lower cost with enhanced productivity and greater sustainability. It will also transform supply chains and the way businesses operate that will result in completely new business models.

AM is a method of making production parts and products directly from design data, building accurate components by adding layers of material to obtain the final shape with minimal waste and no expensive dedicated tooling. It permits radical product re-design and creates new material properties. It is a lead technology, recognised as one of the main manifestations of the Fourth Industrial Revolution.

* AM is a term that is generally used in a manufacturing setting, whereas 3D printing generally covers low cost machines for domestic use. The media frequently refer to both as 3D printing.



A process flow view: Additive Manufacturing

Additive manufacturing will have a radical effect on manufacturing systems, on UK industry and job creation.

What's the opportunity?

The worldwide market for all Additive Manufacturing products and services in 2014 was worth £3.59 billion and is growing at a compound annual growth rate of 31.5% in the last three years, driven by direct part production, which now represents 51.3% (up from 42.6% in the previous year) of the total revenues. This rapid growth is forecast to continue and accelerate over the next decade[1]

The UK is well placed to take advantage of this rapidly expanding market as it is already:

- A global force in advanced technology, life sciences and medical manufacturing,
- Equipped with a strong capability in universities, Catapults and R&D organisations
- At the forefront of the technological advancements in AM.

It is estimated that the UK can win up to 8% or £5bn of this rapidly growing global market for AM products and services, forecast to reach £69bn by 2025[2] and this will have a strong effect on protecting existing jobs (63,000 by 2020)[10] while also generating new employment.

The UK is a world leader in additive manufacturing capability and we have been at the forefront of developing this technology. However, there is a globally competitive race underway with major government backed programmes already established in the US, Japan, Singapore and Germany. If the UK does not capitalise on its position it will likely seed technology leadership, valuable IP and its share of the global market to others.

To enable the full economic potential of AM to be realised, action is required to provide better co-ordination and focus of research, innovation and investment activities and to develop industry-led solutions.

The Challenge

The UK must do more and aim higher

A Steering Group, formed in 2014, has established there is widespread industrial support to address the co-ordination issues and accelerate the industrialisation process of this disruptive technology. It has developed a strategic approach for this purpose and in 2015 it enabled senior industry representations to be made to government.

The Group set out its vision for Additive Manufacturing in 2025:

- The UK as the leading country in terms of exploiting AM
- Direct manufactured AM parts are commonplace in most sectors
- Most of these AM parts cannot be replaced by conventionally made parts economically
- AM is enabling the transformation of existing sectors and providing completely new and disruptive business opportunities
- AM is a fundamental building block of the Fourth Industrial Revolution where every customer's individual product needs are delivered quickly
- High quality, multi-functional and multi-material AM parts are being used
- High value manufacturers which have not embraced AM have lost significant market share

Further work by the steering group has identified five key programmes they will lead that form a framework for UK activity to ensure maximum exploitation of AM technology:

1. **Co-ordination and communication**
2. **Strengthen the industry sectors**
3. **Developing knowledge and skills**
4. **Invest in UK capacity**
5. **Measuring progress**

To ensure successful delivery of the framework's five key implementation programmes, the following recommendations are made:

1. Sector Councils and Leadership Groups[16] should embed Additive Manufacturing in their strategies and identify the business opportunities and barriers related to AM. Co-ordination with the relevant cross-sector activities is also necessary.

2. Trade associations and other institutions involved with the industrialisation of advanced manufacturing technologies should consider the impact of this framework on their areas of expertise and interest and liaise with the Strategy activity to identify areas for joint or co-ordinated activity.

3. Local Enterprise Partnerships and City Regions should use this framework to support and accelerate the industrial exploitation of AM and to position AM as part of their smart specialisation strategy. Local business support programmes should be cognisant of the opportunities presented by AM.

4. Government to ensure alignment of policy and programmes with the strategic needs of AM industrialisation.

5. Public and private sector skills and education providers need to deliver sufficiently trained people to ensure the industrialisation of AM is not held back by workforce shortages. This will involve delivery of high-quality multi-disciplinary education and provide learning at all ages, including through part-time study and workplace training.

6. Industry should work together to design appropriate apprenticeship standards and assessment approaches for additive manufacturing.

7. Standards setting bodies should engage with industry on the development of AM standards.

8. UK Trade & Investment should embed AM within their strategy for the UK regarding inward investment and export.

9. Future funding support for Research and Innovation in AM is required to support the priority needs identified by industry.

10. A single point of focus such as an association for Additive Manufacturing should be explored by Industry and trade associations. A key role would be to raise and maintain awareness, boost adoption and drive collaboration and technology transfer and improve UK competitiveness.

Platform for engagement – your opportunity

The Steering Group's objective is to see the UK achieve the £5bn opportunity by being a leader in AM technology development and exploitation. The Steering Group wants to engage and co-ordinate with government and organisations that support UK industry to align and promote AM activities, to capture investment in capability development and to support research and innovation in the delivery of industry led solutions.

The Steering Group intends to publish a UK Strategy for AM in April 2017 and would like to invite any organisations wishing to contribute to contact any member of the Steering Group, see Appendix One, or directly with the AM programme management team on 02476 647359, by 1st December 2016.

Strategic Context

Additive Manufacturing (AM often referred to as 3D Printing or 3DP) is a key enabler in high value manufacturing where big benefits, such as smarter supply chains, digital manufacturing flexibility, and design freedoms are transforming the way products and components are designed, developed, manufactured and supplied in a wide range of sectors.

This was recognised in the Foresight Report, published by the Government Office for Science, in 2013.[3] AM is a term that is generally used in a manufacturing setting whereas 3D Printing usually covers low cost machines for home use. This often gets confused because the media refer to both as 3D Printing. AM is also referred to in the Foresight Report and by industry as one of the Megatrends alongside Autonomous Vehicles, Advanced Robotics, New Materials, Digital and Biological of the Fourth Industrial Revolution.[4] AM was also listed at number three of the top 21 Tipping Points (moments when specific technological shifts hit mainstream society).[4]

The UK is the 10th largest manufacturing nation and has four of the top 10 universities in the world, all helping to underpin future competitiveness through rapid acquisition of new knowledge combined with innovation and production know-how. Manufacturing value-add in the UK is £168 billion per annum, representing 10.3% of the economy, over 50% of exports and 67% of business R&D. It directly employs 2.6 million people in the UK and 5.1 million across the whole manufacturing value chain.[5]

This makes manufacturing a bigger sector for the UK than financial services, both in terms of GVA (financial services is c. 8% of UK GVA) and jobs (1.1 million in financial services).

Many products include parts made by 'subtractive processes', such as metal shafts made by machining surplus material off, or 'formative processes' such as plastic injection parts made using expensive metal moulds. In extreme cases such as aircraft structures, up to 95% of the high grade aluminium billet is machined away and turned into scrap metal. These processes usually involve large capital investment in machinery and equipment, plus the purchase of special tooling dedicated for each different part.

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

Both cost and environmental imperatives

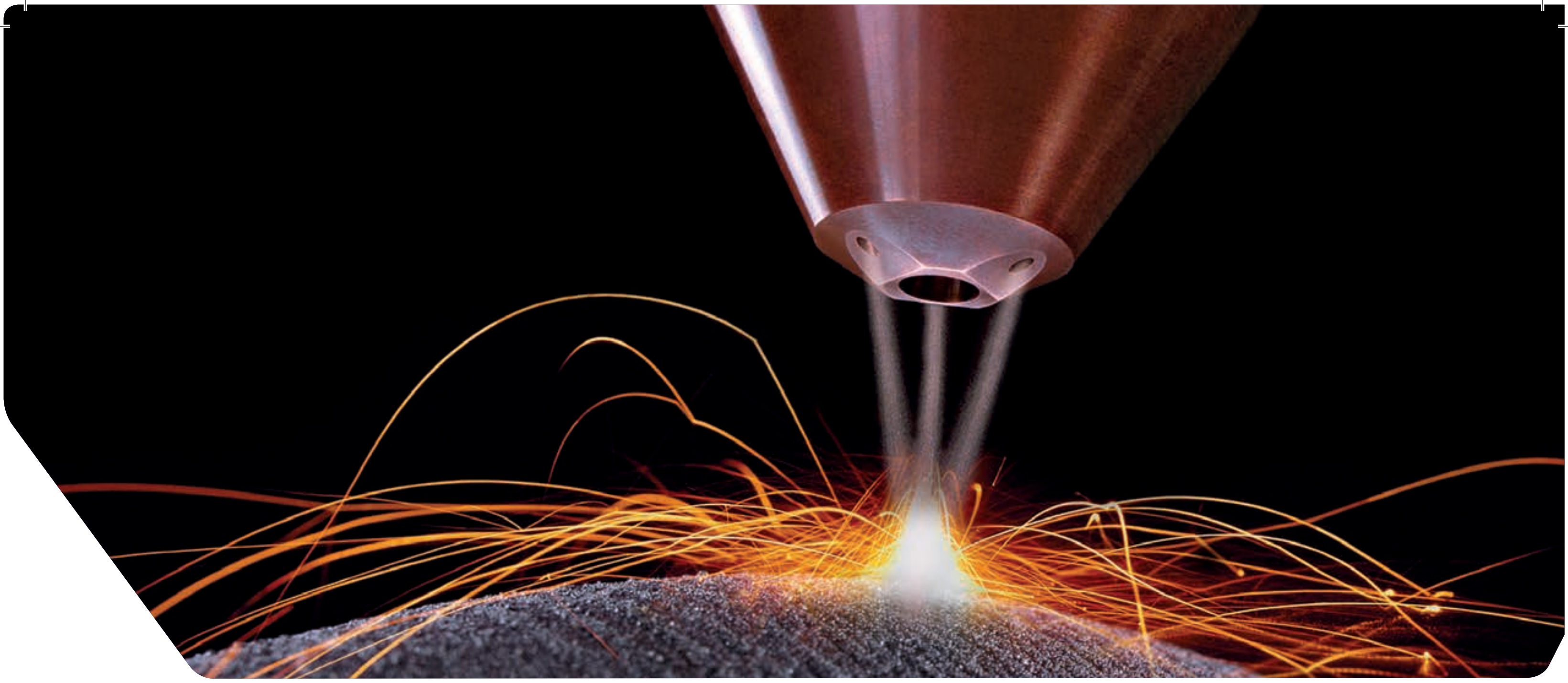
Companies are under pressure to design products with less material, produce them with less energy and enable their use with less environmental impact. This provides lucrative opportunities for UK companies to address these challenges by exploiting the capability of Additive Manufacturing (AM).

Financial viability demands economy of scale (mass production) and the design and material choice is often compromised by the limitations of the manufacturing process. Traditional manufacturing processes can therefore be wasteful and restricting, although fast and 'familiar', and so now is a good time to industrialise AM on a much bigger scale.

There is therefore a compelling business case for companies worldwide, in a wide range of applications including medical, consumer and aerospace parts, for manufacturers to adopt an 'additive' process. These can be more material efficient and allow higher levels of design optimisation and improved operational efficiency for the end user. Additive Manufacturing is a front-runner in advanced production technologies that use digital manufacturing techniques to translate design data directly into products.

Our vision of the world is:

- The UK is a leading country in terms of exploiting AM
- Direct manufactured AM parts are commonplace in most sectors
- Most of these AM parts cannot be replaced by conventionally made parts
- AM is enabling the transformation of existing sectors and providing completely new and disruptive business opportunities
- AM is a fundamental building block of the Fourth Industrial Revolution, where every customer's individual product needs are delivered quickly
- High quality, multi-functional and multi-material AM parts are being used
- High value manufacturers who have not embraced AM have lost significant market share



The Additive Manufacturing (AM) process

AM can make production parts and products, building them by adding layers of material to obtain the final shape. This was first proposed in the early 1990s but has started to become a reality in the last 15-years with over 50% of total revenues today being from direct part production.

A prime example is the production of in-the-ear hearing aids where the bodies for these are now almost exclusively manufactured by AM. Engineering company GE has also stated that 50% of its aircraft engine parts will be manufactured by AM in our lifetime.

AM is being applied commercially in the dental industry for making removable partial dentures. AM provides a range of benefits over conventional manufacturing processes for this and other applications, including less wasted material, the ability to change designs more easily and a shorter process workflow and to reduce labour input by 50%.

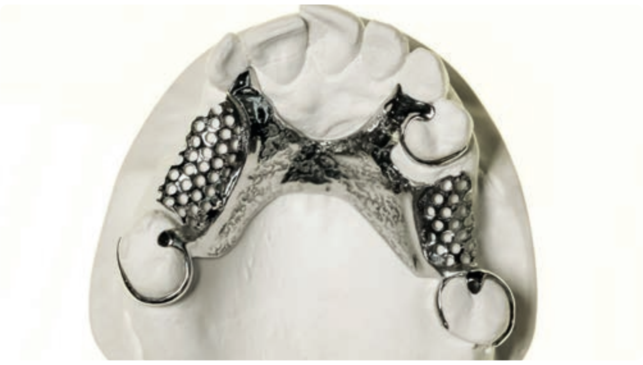


Image courtesy of Renishaw

End use parts

Parts may need finishing processes such as machining but in some instances will be used as made. Although AM has proven to be an invaluable tool for the production of rapid prototypes, it is the recent move into the production of end-use parts which represents the greatest commercial opportunity for the technology. It has captured the imagination of the media and the entrepreneurial 'maker' community, which is starting to be exploited in inspiring young people to take more interest in Science, Technology, Engineering and Mathematics. Often an entry-level 3D printer is the first piece of equipment purchased for a 'maker lab' or so-called garage factory for the new maker generation.

AM comprises a range of technologies, classified by the USA standards body ASTM under seven different process descriptions,[6] using polymers, metals or ceramics - see Appendix 2 for full details. New AM processes are emerging from the research domain to provide multi-materials or embedded products.

The name 3D Printing is typically used for processes that involve relatively inexpensive, desktop machines (priced from £500) making parts in plastic for non-critical applications. At the other end of the spectrum, machines for making high integrity, high performance metal components can cost over £500,000. Recently developed hybrid machines combine additive and subtractive processes on the same platform, often incorporating measuring equipment.

> **3D printing is to additive manufacturing as basic arithmetic is to calculus**
> Sebastian Conran

Novel capabilities of AM

As AM does not require fixed tooling, and can make complex geometries which would have been impossible previously, it has and will continue to revolutionise industrial capabilities.

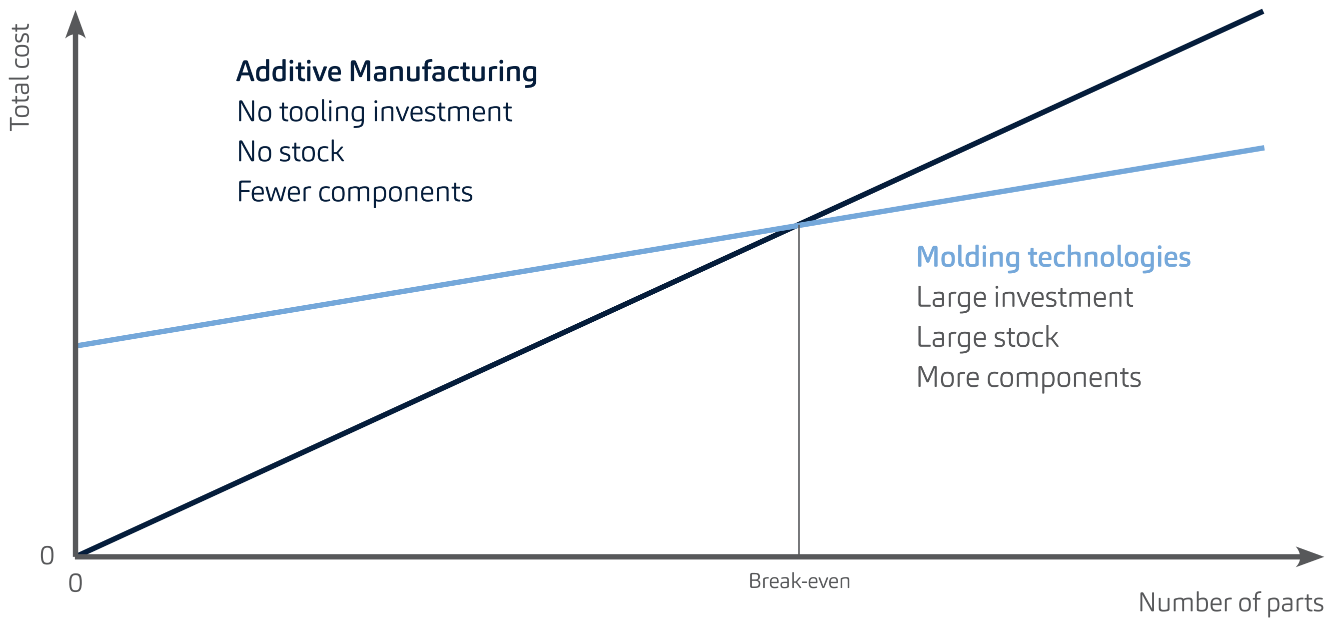
It is highly flexible and hence suited to customised manufacturing, where batch sizes of even just one, become economical and so it enables markets that work better for both businesses and consumers. It is a true cross-sectoral technology with the focus to date being high value sectors such as aerospace, medical, automotive, and consumer products. Applications can be found in almost all sectors, although some will reap the rewards over a longer timeframe due to regulation, technical or economic issues.

Entirely new products

AM has the potential to create novel products, therefore new markets and innovative business models can be exploited. In some industries it is already a strategic capability, providing critical performance advantages in a vital part of a system, such as in a jet engine, without which the whole product would become uncompetitive.

This competitive leverage afforded by AM could increase its net value way beyond the cost of the AM-made parts, by a factor of 10, or possibly 1000 in some cases. This disruptive effect is expected to have increasing future impact when product re-designs become more radical and more frequent.

Additive manufacturing enables batch size of one



Key features of Additive Manufacturing

No tooling
Greater geometry capability
Flexible, customised manufacturing
Novel products, new markets, new business models
Revolutionise industrial capability
Cross sector capability

Case study: Basis Lighting

Basis Lighting Ltd uses laser sintering of nylon to manufacture a variety of parts. Some of its smaller parts are made in batches of about 2,000. The main attraction of AM is that the company can get injection moulded type parts without the setup costs and commitment. It also gives its products a unique touch and makes them more difficult to copy

AM is well suited to customised manufacturing – the "batch of one" – a core feature of the Fourth Industrial Revolution.

The net value of AM as an irreplaceable process within certain manufacturing operations is far greater than the cost of the AM-made part itself, by a factor of 10, or even up to 1,000


EMPIRE
ZTR ARCH EX
PROTECTION
NOTUBES
TRAIL KING

People – a big retraining challenge

AM can be expensive and currently requires highly skilled people including designers, materials specialists, programmers, machine operators and finishing personnel – making it both capital and labour intensive.

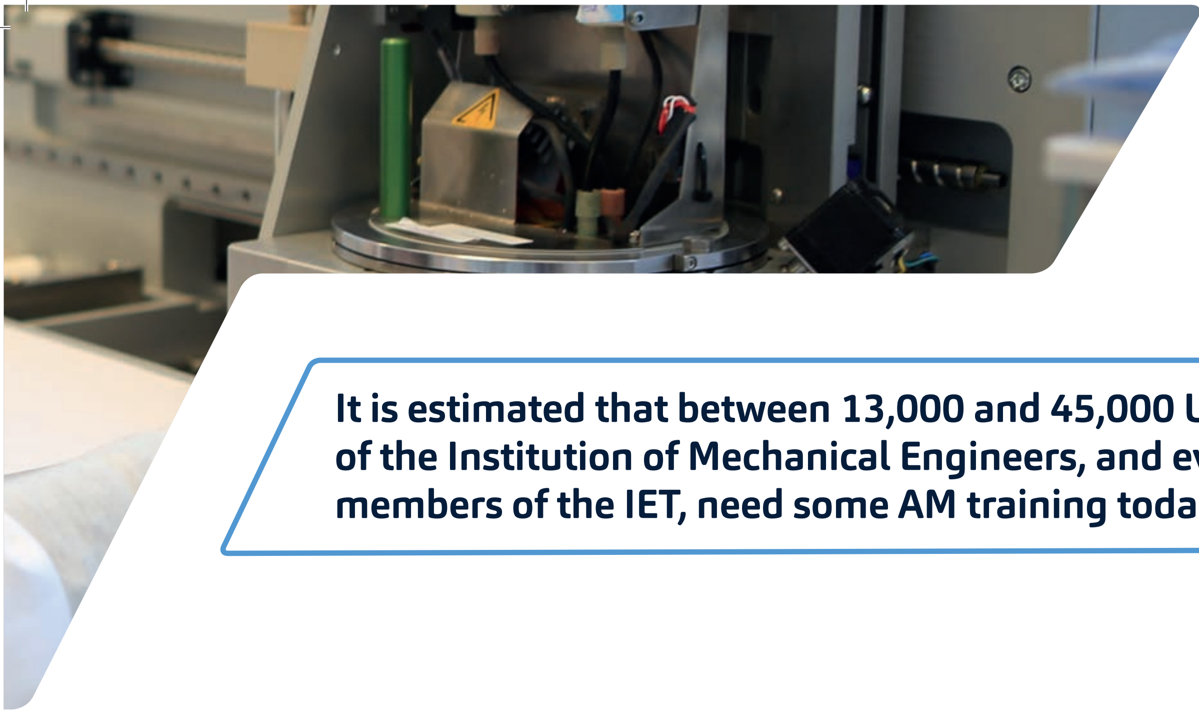
For the technology to become viable in high volume manufacture, one of the challenges is to design out or automate some of the areas which are labour intensive. These are currently high value jobs and many more of them will be needed in the future. If the current engineering skills shortage persists, companies can expect big challenges in securing the required talent.

Initial predictions are that UK industry will need to train around 100 apprentices for AM per year immediately and this will rise to a few hundred per year by 2025. However, the training needed for people already in work is much greater as it is estimated that between 13,000 and 45,000 UK members of the Institution of Mechanical Engineers need some level of AM training. There is likely to be a slightly larger number in the Institution of Engineering and Technology and then an even great number of engineers and designers that do not belong to any institution.

An enabler for Digital Manufacturing

AM is fundamentally about converting designs swiftly into end-use parts, often taking information about the customer's requirement via the internet to the AM machine. The process brings with it many of the productivity benefits of digital manufacturing, an approach which benefits from the integration of cyber and physical systems, also known as The Fourth Industrial Revolution[4] or what is referred to in Germany as Industrie 4.0[7].

The AM supply system will be a seamless, end to end, data-driven process that takes many different customer requirements and then generates a variety of products in single or multiple locations. AM is a tailor-made technology for rapid realisation of this concept of smart, interconnected and responsive production units.



It is estimated that between 13,000 and 45,000 UK members of the Institution of Mechanical Engineers, and even more members of the IET, need some AM training today.

Benefits of the AM industrialisation journey

Industrialisation of additive manufacturing	
From	**To**
Prototyping mindset (batches of one)	Production mindset (batches of one to continuous production)
Companies working in isolation	Networks available for learning and sharing
No national go-to place for AM in UK (our competitor countries all have one)	Creation of national 'Focal Point' (e.g. AM/3DP Trade Association or similar)
No critical mass to identify or solve common technical problems	Co-ordinated activities to build critical mass to ensure key issues are addressed
Disconnected agendas and projects in public funded research & innovation	Cross-sectorial activities providing key linkages and identifying common agendas
Science-based operators and craft skills	Trained technicians and production operators
Isolated machine platforms in labs	Smart production in cyber-physical networks
Lack of awareness and access to AM/3DP expertise for UK businesses	AM/3DP awareness programme running nationwide as a key activity

The UK's capability

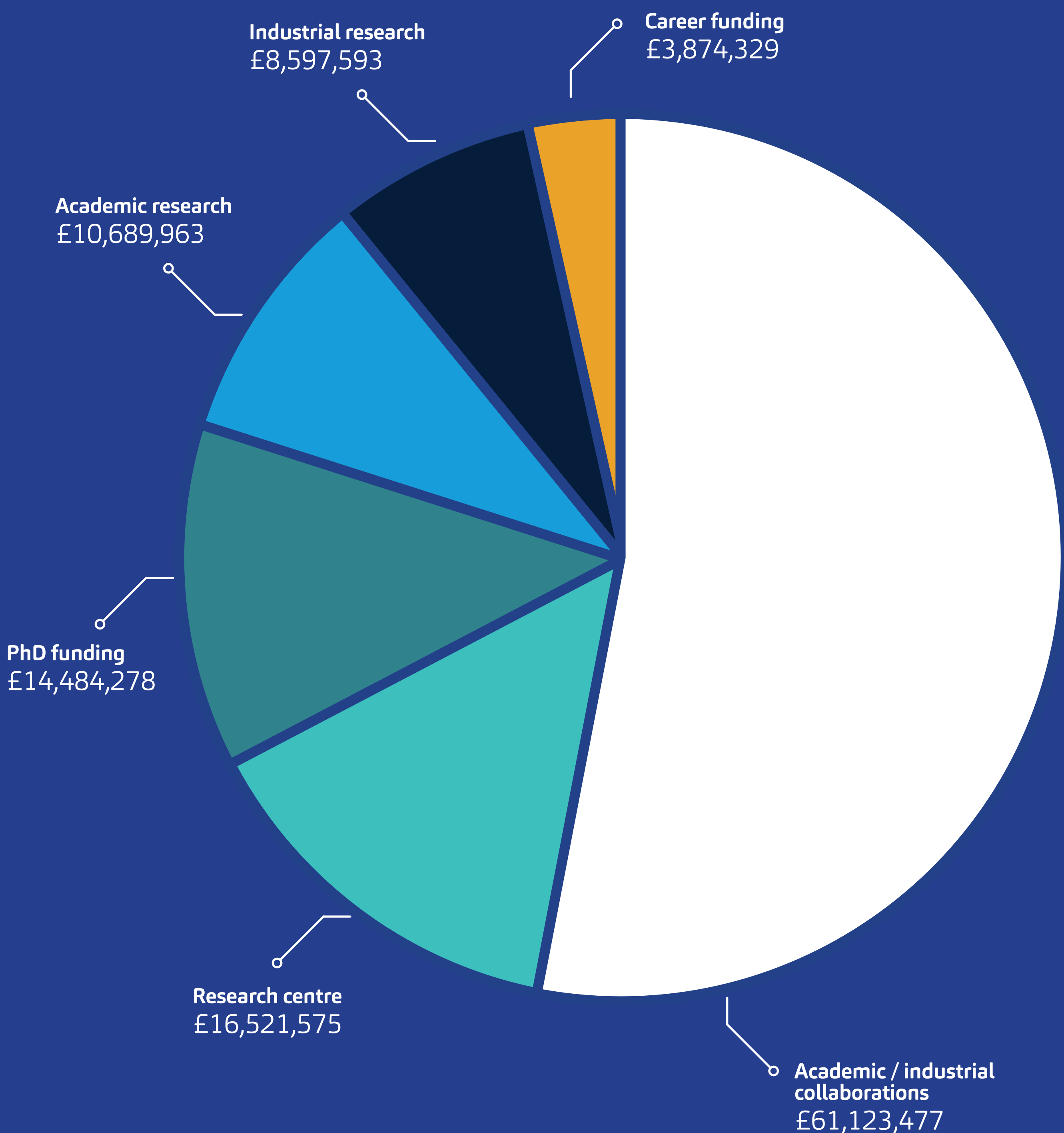
At a glance

- AM research funding has doubled since 2012 to over £30 million
- Number of organisations involved in AM has doubled to 250
- The deeper AM supply chain is a key USP for the UK and should be developed
- Mix of public and private funding shows AM has the right balance of commercial returns and stability
- Initiatives like the HVM Catapult's REACH help small companies to understand and exploit AM technologies.

The UK has a solid foundation of companies applying AM within product development activities for prototyping and tooling. UK researchers have also led the transition from prototyping to manufacturing end-use parts and this new area is seeing commercial exploitation by a range of companies from small start-ups to global companies such as Rolls-Royce plc , GSK and GKN Limited.

The UK is a world leading source of AM related knowledge and research activity. The recently published UK Research Mapping Report[8] found that research funding has 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.

Types of research activity being funded



This activity helped a nascent supply chain to develop. This includes one of the world's leading machine suppliers (Renishaw), a leading material supplier (LPW), software developers (including Autodesk), AM part suppliers, technology providers and research groups. The new and dispersed nature of the developing supply chain has led to a relevant work group – the UK Additive Manufacturing Steering Group – focusing on the need to establish the supply chain as part of the UK national approach.

The UK has an EPSRC Centre for Innovative Manufacturing in Additive Manufacturing but there is also activity in other EPSRC centres and a wide range of publically funded projects supported by EPSRC, Innovate UK and other bodies as well as significant, but not necessarily well connected, private venture funding from large and small companies.

The industrialisation of AM will rely on support for industry from many stakeholders. In the short to medium term this will involve assistance from knowledge holders in taking applications and technical innovations from proof of concept to production scale activity.

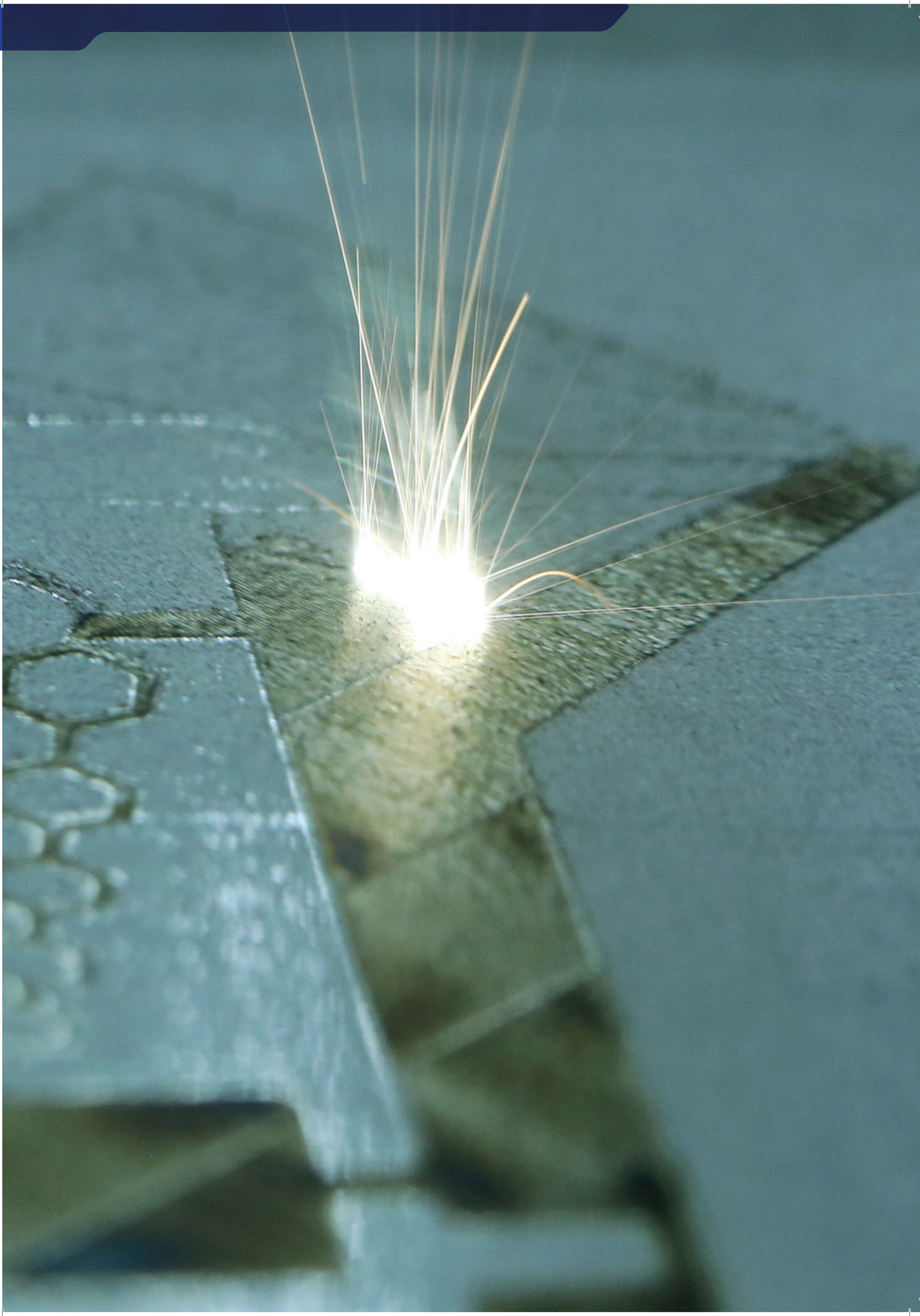
The High Value Manufacturing (HVM) Catapult is committed to supporting more effective use of AM by the UK's manufacturing sector.

The National Centre for Net Shape & Additive Manufacturing, established at the Manufacturing Technology Centre in Coventry in 2015, provides a focal point for innovation in AM within the HVM Catapult taking technology developed in universities through to commercial exploitation in collaboration with industry. In addition to supporting adoption of AM by large organisations, new initiatives, such as REACH, have been launched by the HVM Catapult to enable SMEs to explore the capabilities of AM technology.

There is also a range of Research and Technology Organisations that support the UK research and innovation activities, such as TWI (The Welding Institute).

Additive Manufacturing offers unrivalled flexibility, enabling complex parts to be printed on demand using novel material compositions. The High Value Manufacturing Catapult will continue to support cross sector collaboration and sharing of knowledge to ensure that the UK can take full advantage of this revolutionary technology, which will affect the way products are designed, manufactured and even supplied to customers in the future...

Dick Elsy, CEO
High Value Manufacturing Catapult



Wealth creation from UK research into AM

This activity has led to a number of start-ups and wider economic benefits. Examples of these are:

Phil Reeves was a Research Assistant on the first EPSRC Rapid Prototyping project which eventually led to the formation of Econolyst and now Stratasys Strategic Consulting which is based in the UK.

Rapid News was launched by Warwick Manufacturing Group (Warwick University) in 1992 and was then sold to a commercial media company who set up Time Compression Technologies (TCT) which has its HQ in Chester and arranges AM events across the world.

Richard Hague and Phill Dickens of the University of Nottingham invented Quickcast 2.0 to make stereolithography patterns for investment casting. This has led to the manufacture of millions of castings by this technique worldwide.

Buckinghamshire College Rapid Prototyping centre has become one of the largest 3DP bureaus in the UK and was eventually purchased by 3D Systems.

Adrian Bowyer at Bath University developed the RepRap project that led, with other innovations, to the open source maker movement.

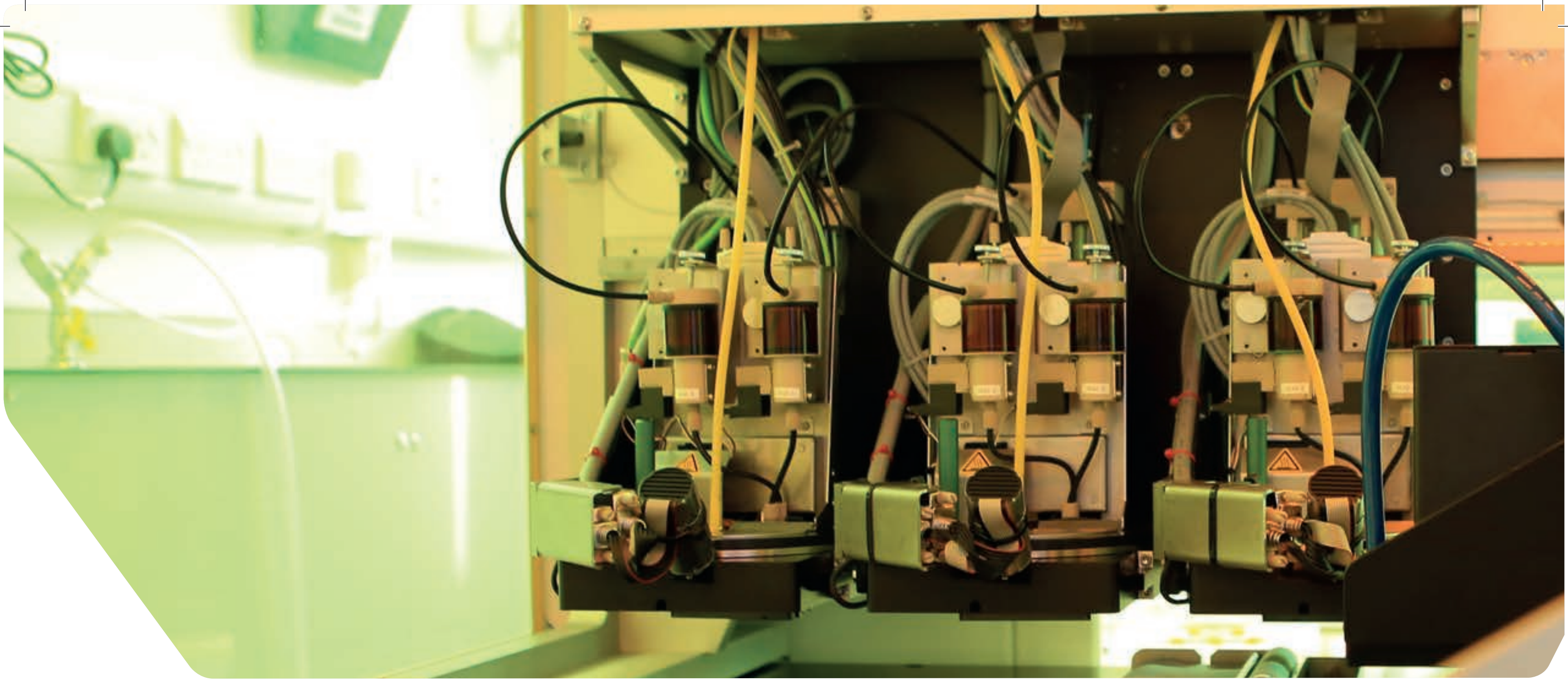
Phil Carroll worked on commercial and government funded AM development at TWI and then founded LPW, one of the leading powder producers for AM and announced as a winner of a Queen's Award for Enterprise in International Trade 2016

Work within the National Net Shape & Additive Manufacturing Centre and across the whole of the High Value Manufacturing Catapult is helping UK industry to research into and exploit AM techniques, including world leading hybrid AM processes

Neil Hopkinson was lead inventor of polymer sintering (High Speed Sintering) developed at Loughborough University. This has led to a strategic partnership with Evonik Industries AG and the partnership has subsequently licensed the portfolio to several equipment manufacturers.

Hybrid Manufacturing Technology Ltd, which designs and builds award winning hybrid AM systems in the UK, was formed as a spin out from the Innovate UK funded RECLAIM project

Added Scientific Ltd was spun out of the University of Nottingham



Fragmented industry risks AM progress

Even with this activity, industry recognises weaknesses in the supply chain such as in materials supply, equipment, post processing and validation.

The UK Research Mapping Report also found that many of the barriers to the adoption of AM and limitations of the technology identified in a 2012 innovation report[2] are being addressed through research and innovation projects. However, a major risk to effective commercial exploitation now is the UK Research Mapping Report's observation that:

"The manufacturing community in the UK is highly fragmented with organisations only networking through projects rather than through a structured network, community of interest or association."

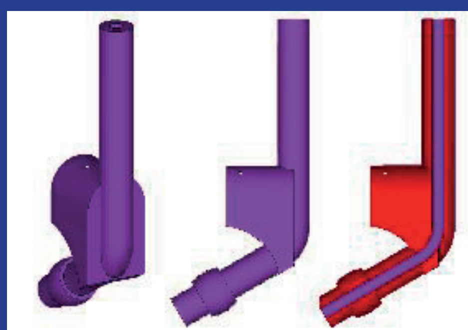
It is also recognised that research into AM will need to continue to feed the pipeline of future innovation.

In 2013, a Manufacturing Foresight Report Evidence Paper[9] recommended that the UK should develop a National Strategy for Additive Manufacturing. 'Additive Manufacturing UK' – and its purpose to accelerate industrialisation of AM and create the conditions in which all UK businesses can thrive – is a direct response to that earlier recommendation and builds on the Industry Positioning Paper[10] presented to Government in spring 2015.

AM will develop new capability for ‘4D Printing’, where the fourth dimension is time.

AM in action: BAE Systems and 3T RPD

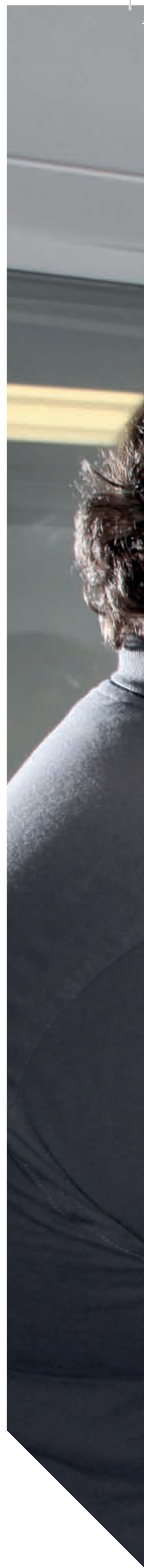
BAE Systems Regional Aircraft worked with 3T RPD Ltd to provide spares of a small breather tube that forms part of the cabin windows and stops the windows misting up on one aircraft platform. Not only was there significant time saving and the avoidance of the tooling cost to machine the part, but the actual parts cost 60 per cent less than when manufactured using the traditional method.



In an industrial context, AM is “another tool in the toolbox - but a very significant one” and will not replace all aspects of current manufacturing technologies. However, AM will develop new capability into what some people refer to as ‘4D Printing’. This phrase tends to be used to cover two different scenarios:

- Where parts or products will change over time (hence time is the forth dimension). Likely applications are stents which expand in the artery or printed tissue that grows at a later stage
- Where parts have controlled deposition of material composition such as in tablets in pharmacy or electronic items made by multi-material processes.

Realising the business opportunity



The economic opportunities for all UK sectors

Flexibility for the future

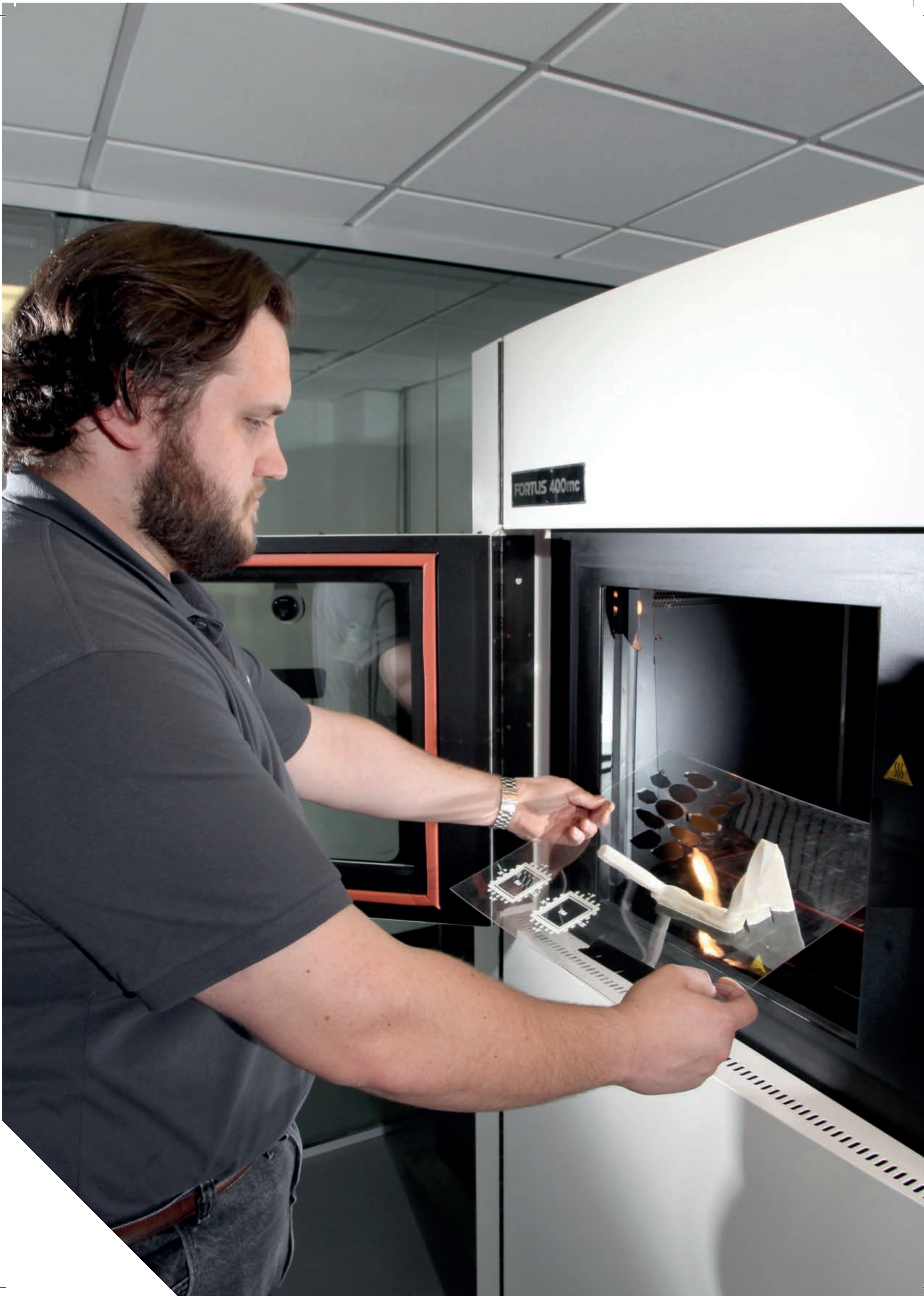
In future manufacturing systems, flexibility will be king. AM offers unrivalled flexibility enabling business to design and make better products, respond more quickly to changing demands, address new markets and explore new business models, as well as harnessing the benefits of digital manufacturing to provide a crucial competitive advantage in the 21st century market of ideas.

Companies will be expected to design or modify products, set up the manufacturing, print/ produce a batch and dispatch to the customer in hours not days. AM can realise this where conventional processes cannot.

Beyond AM's existing role in rapid prototyping and tooling, the value of its adoption for direct production of end-use parts is now recognised by most industry sectors including:

- Aerospace
- Automotive including motorsport
- Consumer goods including sport, leisure and jewellery
- Defence
- Energy
- General industrial products including machinery and equipment
- Health, pharmaceuticals and medical equipment
- Space
- Transport including rail and marine

Some sectors are ahead of others in identifying benefits and/or implementing the technology but it is difficult to find a sector where AM is not relevant.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Diverse business opportunities

Supporting these product areas are significant business opportunities in professional services, ICT/digital services and the AM supply chain, which involves the provision of materials, machinery, software, system integration and consultancy services.

Early adopters of AM have exploited niche markets in medical/dental equipment, non-structural aerospace applications, motorsport and consumer goods. Strategy development activity has indicated that each sector has different views of the wider business opportunity, each with differing reasons for interest in a particular material or AM technology type.

The business case for using current AM technology is strongest when it involves a unique, customised or complex design requirement coupled with low or moderate production volumes (batches of 1 to multiples of 1,000s). As the technology progresses then much higher volumes will become possible and this will open up large areas of additional market opportunity.

AM offers the opportunity of localised and flexible production and this is being investigated by several projects within the EPSRC Redistributed Manufacturing programme. It is a key enabler for many High Value Manufacturing applications as well as for part repair and life extension.

Critical mass is essential

To realise these diverse opportunities and anchor sustainable value-add in the UK, we need to establish critical mass in design, application and production know-how. The capability of the sectors and companies using AM needs to be strengthened by providing the necessary expertise and supporting infrastructure, mobilised through professional services companies and other organisations. This will allow new manufacturing value streams to be created.

Having this critical mass in the UK will maintain and grow the UK's status and reputation as a global trader and enable domestic and export sales of AM parts and of manufactured assemblies and systems containing key components made by AM. Overseas companies looking at AM will be more attracted to invest in the UK if we can demonstrate effective, core capabilities in AM technology, linked to production supply capacity and services.

It is now important and urgent to recognise AM as a strategic technology to underpin the ability of UK manufacturing companies to remain competitive in all these sectors as the disruptive impact of AM starts to take hold. AM is already highlighted as a strategic enabler by the Aerospace Growth Partnership, the Advanced Propulsion Centre, the Advanced Materials Leadership Council, the Engineering and Machinery Alliance and the Ministry of Defence, as well as many other manufacturing related organisations.

AM has already become a crucial lever to enable some companies to compete. For example, having one critical component made using AM within a high performance system, such as a jet engine or F1 race car, can transform the performance of the entire product and make the difference between commercial success and failure.

The unique value to be gained by specifically designing for, and manufacturing by, AM is clear. Whilst not suitable for every component, we cannot perceive the advancement of power systems without the concurrent industrialisation of AM

Neil Mantle, Rolls-Royce plc

UK industry wants AM

Leading UK manufacturing companies have stated that they need to exploit AM, and to understand more precisely where and why it can improve their competitiveness.

Image courtesy of Rolls Royce

In late 2015, Rolls-Royce plc flight tested the world's largest aero engine component to be manufactured, to date, using AM. The 1.5 metre diameter significant load bearing structure for its XWB-97 engine development programme was made up of 48 large titanium aerofoils manufactured and then joined using advanced Electron Beam Melting AM and Electron Beam Welding techniques. Normally made from cast or forged components, the additive manufacturing technique eliminated the need for the complex fixed tooling associated with these methods, allowed more time for design and concurrent manufacturing engineering and reduced the end to end lead-time for the first development structure by 30% while ensuring component integrity and airworthiness.

The UK now has a major technology-driven business opportunity and is well placed to capitalise on our previous and current research and innovation developments. The technology is already mature and being used widely in some sectors, although the lack of international standards for AM is restricting its take-up in some sectors. There is a window of opportunity to act now and use the next three to five years to build solid foundations for full scale industrialisation of this technology across most sectors.

UK inventiveness in design at a practical level is recognized internationally and an example of this is the UK's strength in architecture. However, the UK can exhibit less strength in exploiting a technology on a wider scale. We should not let this happen with AM.

The market for AM: Global and UK

At a glance

- Global market for AM products and services worth £3.59 billion in 2015 and growing at 31.5% annually
- The UK represents 5% of the global market – huge potential to capture market share
- Economic analysis indicates that AM adoption in the main industry sectors will impact around 100 different industry activities
- +£5bn industry: Value to the UK economy attributable to AM produced parts will be around £1bn in 2020 rising to £5.6bn in 2025 (approved forecasting method)

The worldwide market for all AM products and services in 2015 was reported to be worth £3.59 billion and growing at a compound annual growth rate of 31.5% in the last three years[11], driven by direct part production, which now represents 51.3% (up from 42.6% in the previous year) of the total revenues.

The UK currently represents around 5% of the global market and is well placed to exploit the predicted growth in AM with a strong high value manufacturing sector supported by the Catapult Centres and underpinned by world leading university research.

Published data on the current and forecast value of AM to the UK in each of our main industry sectors is not available, but a preliminary economic analysis done within the strategy development activities would indicate that AM adoption in the main industry sectors will impact around 100 different industry activities, as defined by the Standard Industrial Classification (SIC) codes (see Appendix three).

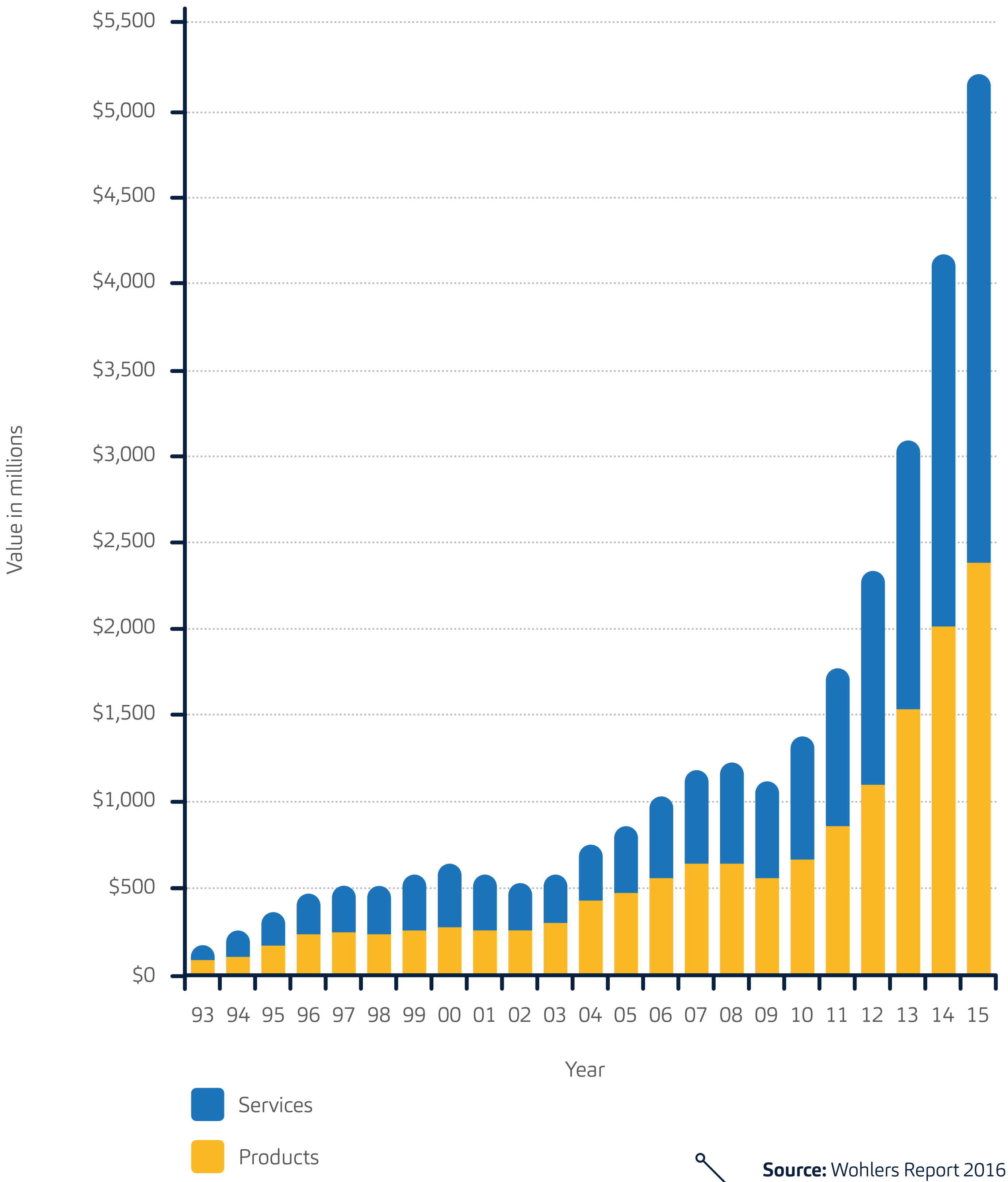
The analysis method covered the full AM value chain and included manufacturers, their supply chains and the associated service industries. By estimating the market value penetration of AM at this level of granularity based on Annual Business Survey data[12], it was calculated that the gross value-add to the UK economy attributable to AM produced parts will be around £1bn in 2020 rising to £5.6bn in 2025. This growth of AM could lead to growth of the manufacturing sector generally with an associated increase in employment.

The need to act now

Recent reports from China, Germany, Japan, South Korea and the United States[13] show that AM is recognised as a strategic technology around the world – and one which must be mastered and exploited if countries wish to remain competitive in a global manufacturing market. Actions resulting from these national AM strategies are helping other countries to improve their co-ordination of research, innovation and commercialisation of AM activities.

Many countries benefit from a flourishing AM support network (e.g. The Society of Manufacturing Engineers' Rapid Technologies & Additive Manufacturing Community in the USA), which helps to connect the AM community to share knowledge and best practice, as well as fostering key research and commercial collaborations. Although the UK has a good informal network, as can be seen by the examples of innovation success in the 'UK Capability' section, it is slow and inefficient in growing the network.

Value of the worldwide AM market



Source: Wohlers Report 2016

Challenges of the UK system

AM is often represented as a subgroup within a UK trade or professional body (for example the AM special interest group within the Association of Industrial Laser Users) and these activities tend to have a relatively narrow technology or sector focus. UK industry is placed at a significant disadvantage by the lack of a single point of contact to represent the AM business opportunity.

A more general threat to our ability to compete in the rapidly growing AM market is the fragmented nature of our domestic manufacturing supply base, coupled with a number of significant market failures such as:

- insufficient design knowledge for AM capability
- a severe skills shortage – both in general engineering and AM expertise
- lack of awareness in the benefits of AM
- a need for companies along the supply chain to share knowledge and work collaboratively to successfully exploit AM
- difficulties in understanding the cost models and investment case for AM

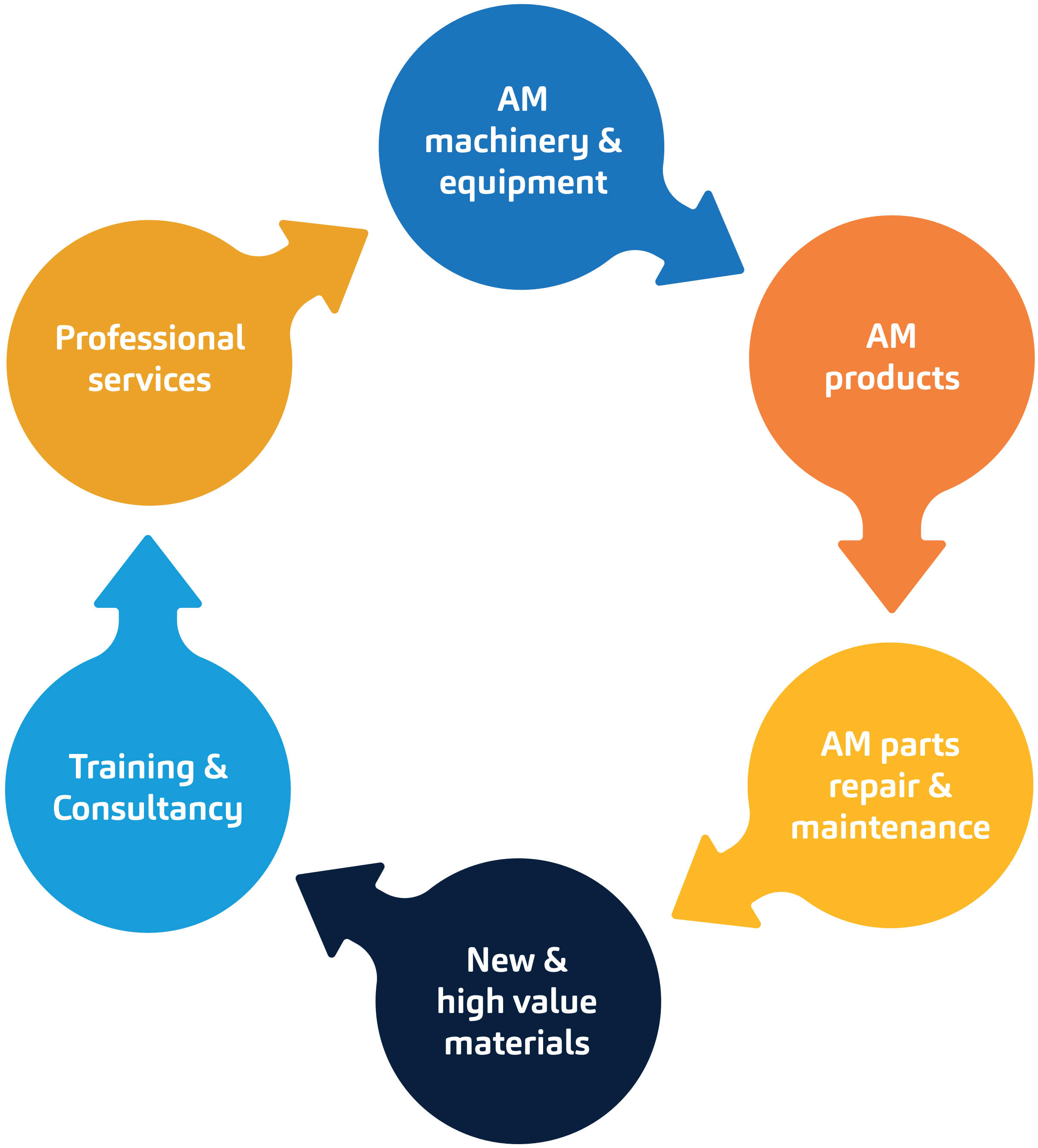
AM expertise will attract global companies' investment

The portability of AM equipment, which enables small and medium companies to establish a manufacturing location without major capital investment, also makes it easy for multinational companies to locate production wherever they find the greatest efficiencies. So to ensure existing UK manufacturers can acquire AM capability, and to attract new entrants to invest in the UK, strategic action is urgently required to anchor both human and physical AM assets.

This will enable a more robust foundation for securing exports of AM-made parts and manufactured items containing such parts, plus machinery, equipment and services, including education and training. It is also important that we lead in the sphere of machinery design and manufacture, providing end to end supply chain in the UK. At the same time, the landscape of technical, financial, skills, regulatory and political support for would-be AM producers in the UK needs to provide a co-ordinated network to reduce the risks for businesses in their transition to AM capability.

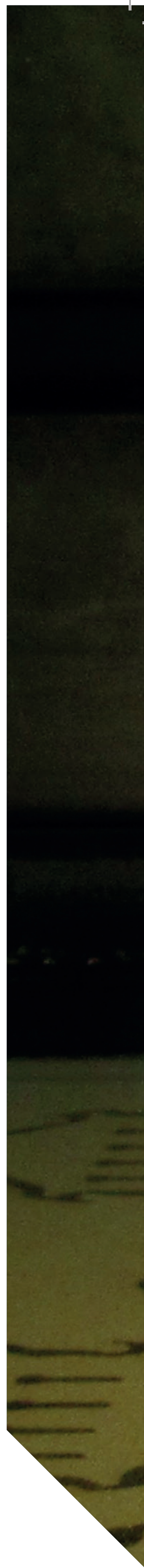
If we do not act boldly now then others will and the opportunity will be lost.

Although the UK has a good informal network for connecting AM expertise, it is slow and inefficient in growing the network compared with the national strategic approach of competitor nations.



AM's total value opportunity to the UK

Our Approach



What we have done

The development of the UK strategy for AM began in 2014 when a small group of industrialists, academics and the authors of this report converged. They all had many years of experience in rapid prototyping and were pioneering its use for additive manufacturing. This group developed a proposal for a UK strategy and, after extensive consultation with 10 senior industry figures made representations to government about the importance of AM and the need for concerted action.

The strategy development process started in 2015 with the gathering of inputs from a wide range of stakeholders in industry via workshops and online calls for evidence[14]. These highlighted a number of different gaps, barriers and priorities. Several pilot activities were run to explore these in more depth in different industry sectors, using stakeholder feedback to refine the approach and develop industry-led solutions. This also clarified what we should aim to be doing at national level, i.e. as a cross-sector strategy activity, and to separate this from what is best done within the different industry sectors, also recognising that some things are naturally done at company level, often in a confidential setting.

Based on the results of the evidence gathering and pilot activities, the high level structure is best defined in terms of five key programmes.

However, it should be emphasised that this strategy development for AM is very much a continuous process as the technology develops but key results will be achieved over the next year. The following are key components of the framework for the UK to ensure maximum exploitation of AM technology.

01

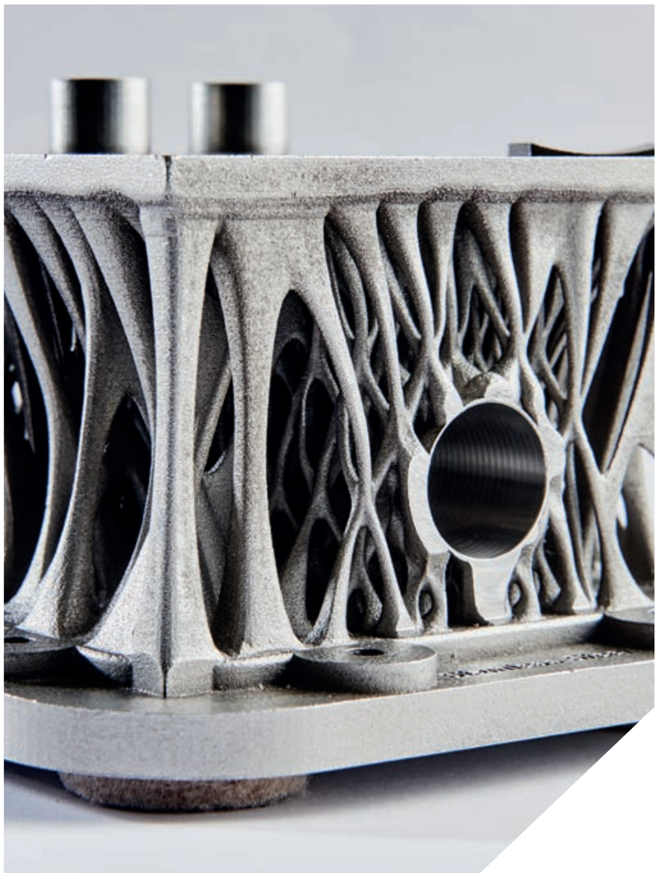
Co-ordination and communication

There is a need for better co-ordination of problem-solving activities across industry sectors in the UK.

This AM programme is divided into several Thematic Workgroups, each focusing on the key priority areas as highlighted in the evidence gathering phase. The pilot phase work up to this point has involved representatives from several industry sectors and trade associations plus relevant expertise from academia and professional organisations, establishing thematic groups for:

- Cost/ Investment/ Financing
- Design
- IP creation, protection and data
- Materials and process
- Skills/Education
- Standards and certification
- Test and validation

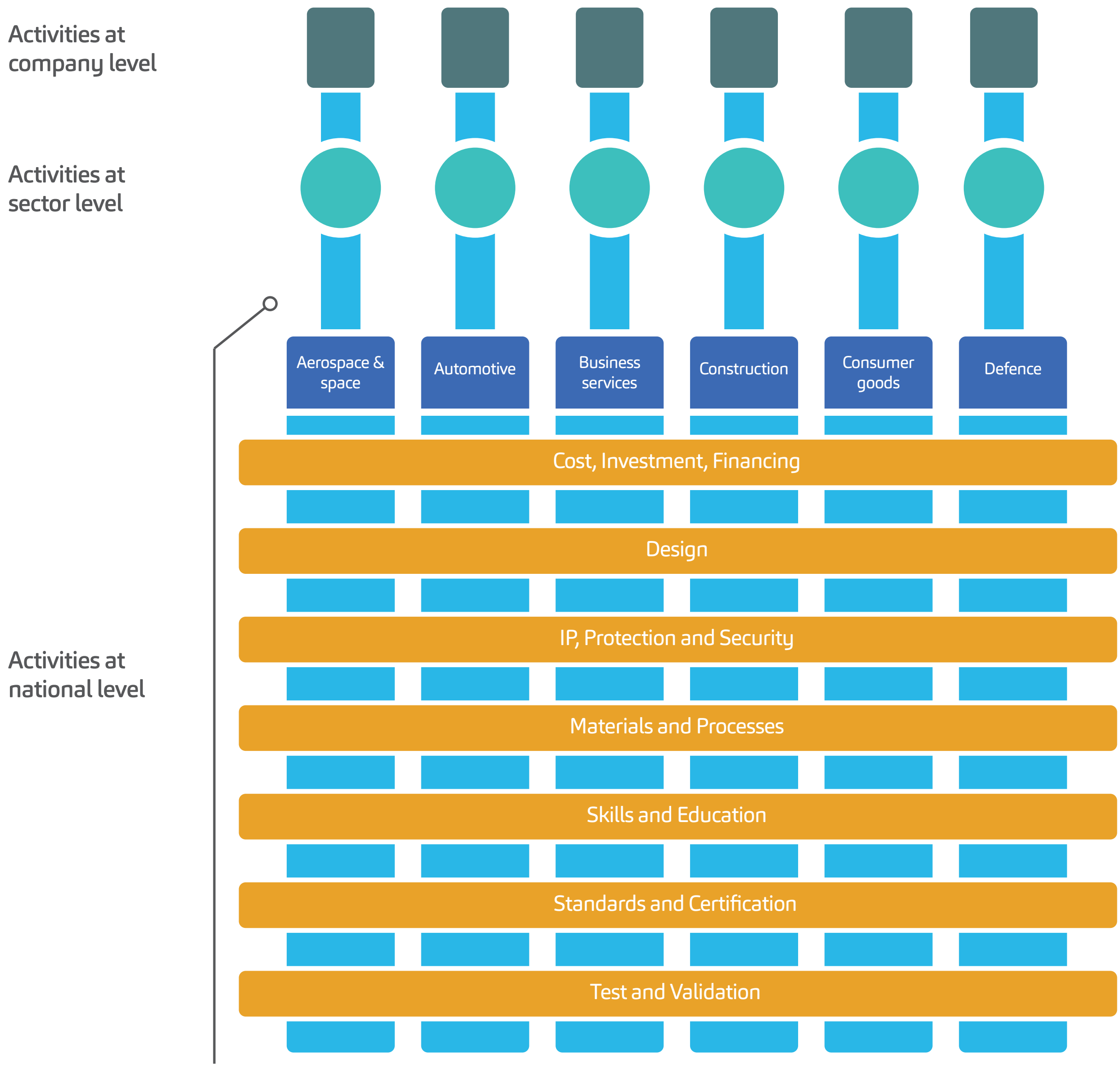
While the scope and content of these groups are expected to change over time, a summary of the groups and their remits today is shown in the following table.



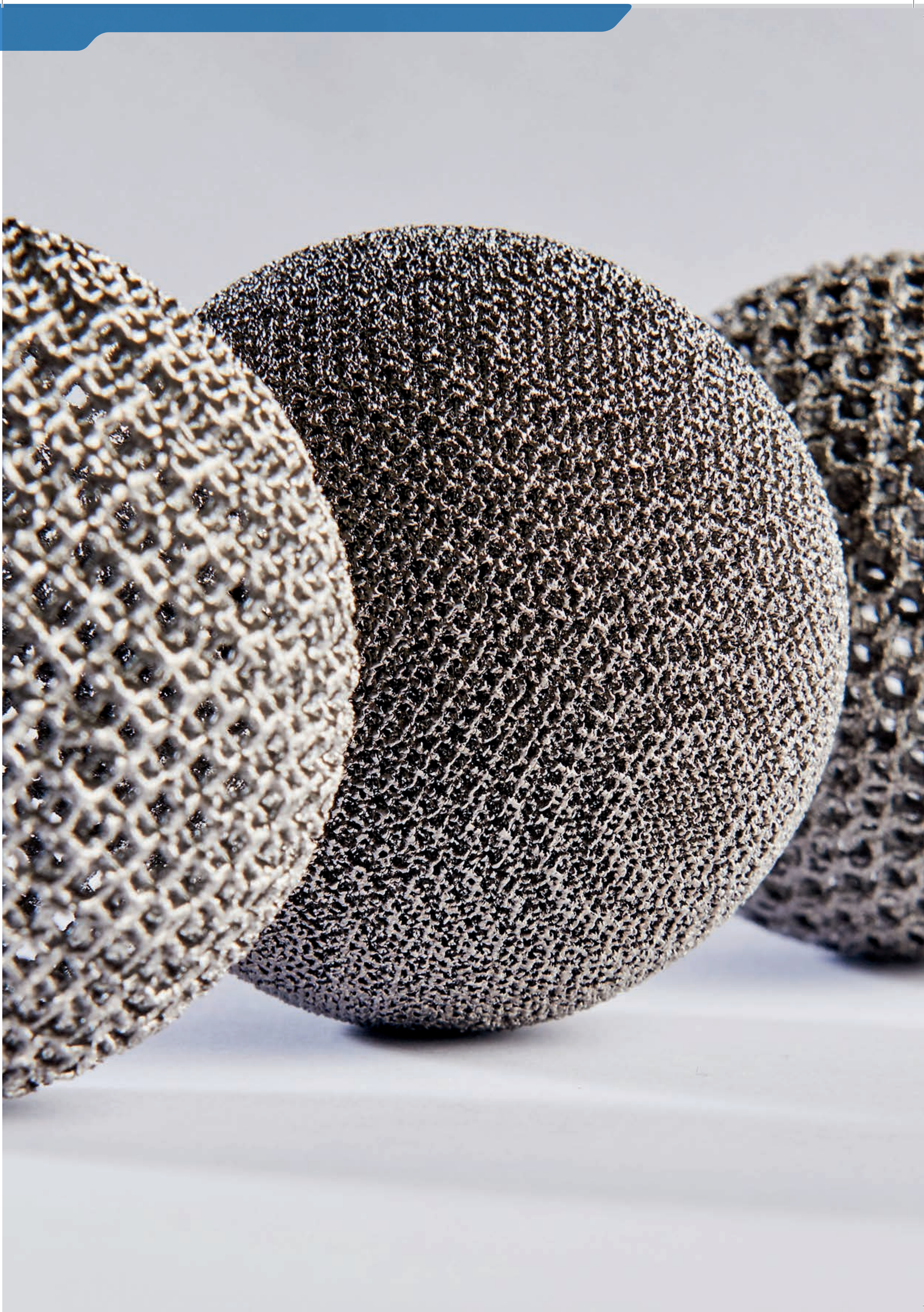
Thematic Workgroup	Summary of common perceived barriers
Cost/ Investment/ Financing	Funding to increase awareness and reduce risk of adoption (testing, scale-up, machine purchase) – especially for SMEs, understanding of full costs (including post-processing, testing), and cost of materials
Design	Need for guides and education programmes on design for AM. Better understanding of design for AM constraints, availability of AM-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 AM. Global IP leakage. 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

Interfacing thematic workgroups and sectors

The workgroups operate within themes and across sectors. The schematic shows a sample of the cross-sector matrix structure in which these workgroups operate.



There is a need for better awareness activities and a national point of focus for people to find out about AM, preliminary discussions have commenced with trade associations and other organisations interested in this area.



02

Strengthen the industrial sectors

Our approach recognises that most of the 'heavy lifting' for technology development takes place in the industry sectors. Each sector has its own timescales, with different business cases/drivers and different requirements and barriers to entry for their respective markets.

Because it has been estimated that AM has near-term application potential in most UK industry sectors[10], this report advocates that each sector establishes an AM workgroup activity, noting that some already have one up and running.

This structured approach with both sector-based and thematic (cross-sector) workgroups supports the needs of all the relevant industry sectors, including those such as machinery and equipment and professional services, which are in themselves cross-cutting.

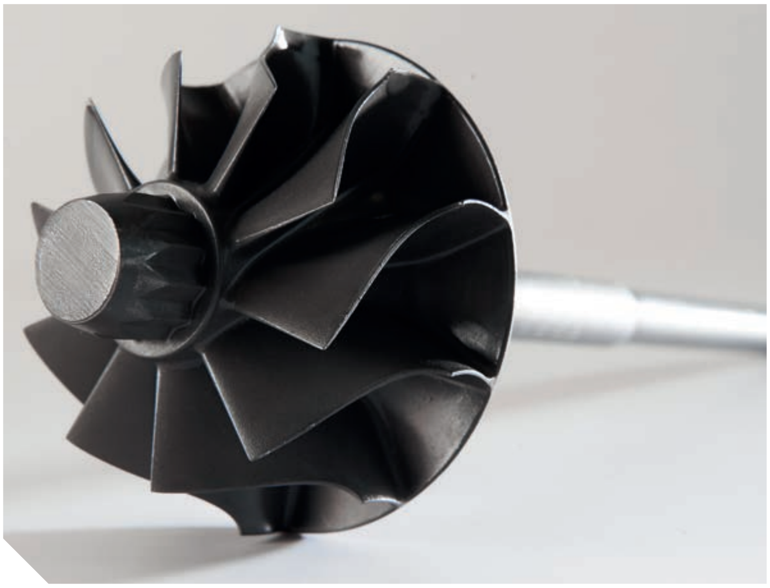
An 'engagement' process has been piloted in several sectors to enable key manufacturing professionals with an interest in AM to progressively engage with the thematic workgroup process while developing their own sector view of opportunities, barriers and priorities for the industrialisation of AM. This enables two -way communication between the groups, strengthening the individual sector activities by feeding in what has been learnt in the thematic groups, while providing a channel for all the sectors to get common issues on to the agendas of the thematic groups. This will also need input from the various trade associations.

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

Zoe Webster,
Head of Manufacturing,
Innovate UK

03

Develop the knowledge and skills



Developing the right skills in sufficient numbers to support industrial growth is essential to realise the full potential of this technology. The cross-sector programme covering skills, education and training has already engaged with a number of relevant education and training organisations as part of the pilot process.

The scope of this programme includes the full spectrum of AM technologies and people, from those doing 3D printing of plastic parts and precious metal jewellery through to those in the manufacture of complex titanium parts for aircraft engines or medical implants. This will be vital to ensure the delivery of the predicted number of AM trained apprentices (around 100 per year rising to 300 per year by 2025) and also retraining of people in work (tens of thousands).

Power of the network: Our approach seeks to build bridges and open up collaborative working opportunities between different groups of people in these diverse occupations whose paths don't normally cross. Developing a thorough understanding of the common skills and training needs across these different groups of designers, makers, materials specialists and process technicians is a key priority for this programme area. There is a need to deliver high quality education and provide adult learning, part-time study and workplace training.

04

Invest in UK capacity

This programme aims to accelerate the deployment of physical assets by helping to mobilise the associated financial, technical and government support required for industrialisation.

It also needs to help various stakeholder organisations in the public and private sector to get better levels of understanding about AM and hence better alignment and co-operation across the technical, political, financial and geographical infrastructure in the UK.

The thematic group covering cost and finance is central to this programme and the pilot phase has enabled the group to establish critical mass. It will also be able to provide better networking around access to finance and funding, including UK and international sources. The groups on standards, testing and IP are also expected to make important contributions to this programme activity, to help companies gain confidence, reduce risks and progress faster towards investment in AM supply chain and production capacity.

Currently there is not a supply chain that can deliver qualified materials to a standard suitable for high quality manufacturing, and robust material data and process parameter information does not exist to give sufficient confidence to manufacturers. If we could achieve this with UK suppliers, it would be a competitive advantage for all of the UK AM industry. It would also be better equipped to focus on the opportunities created by government policy, UKTI activity and initiatives such as Local Enterprise Partnerships, Growth Hubs and Smart Specialisations.

Currently there is not a supply chain that can deliver qualified materials to a standard suitable for high quality manufacturing. Robust material data and process parameter information does not exist to give sufficient confidence to manufacturers

05

Measure progress

It is essential for our approach to measure progress against the stated objectives.

How can we measure the rate of industrialisation of AM, how do we know if its full benefits are being realised, what is the real value-add to the UK economy?

Currently the majority of available economic data on AM market size and forecast growth is based on the sale of equipment (machine platforms and associated materials and services). This is generally aggregated to national or global level. We have been unable to identify existing economic data for AM of end-use parts at UK industry sector level. A new economic model has therefore been developed based on Standard Industry Classification (SIC) codes; it links these to the Annual Business Survey in order to identify annual GVA by industry activity.

This method will allow the definition of which activities are in which 'sector family' at SIC code level – see Appendix three. By making an estimate of the proportion of that value that AM is expected to represent in the future at SIC code level, for example in five and 10 years, an initial estimate of future GVA attributable to AM has been made for all the relevant industry and business activities in the UK associated with the AM value chain.

The value of AM-made products will generally be higher than those they replace, so the method has not taken account of any economic displacement effects. This approach is similar in concept to the method of assessment advocated in the recently published Manufacturing Metrics Report[15].

Driving all five programmes is our overriding purpose to enable UK industry to realise the full benefits of Additive Manufacturing (including 3D printing).

In the absence of published data to quantify the future opportunity for the UK in AM for end-use parts, our preliminary economic analysis puts the potential GVA at £1bn by 2020 rising to £5.6bn by 2025. Our approach is targeted on the UK achieving this market objective.

Digital fabrication technologies such as additive manufacturing have the potential to transform the industrial landscape. It is vital that the UK now co-ordinates its efforts on building capabilities to ensure that UK firms of all sizes operating at all stages of the value chain are able to create and capture value from the use of these technologies

Professor Andy Neely,
Head of the Institute for Manufacturing,
University of Cambridge, Department of Engineering

Our commitment to implementation

- Roll out the pilot programmes into full implementation of the thematic groups together with engagement of all the relevant industry sectors in the strategy activity
- Develop the dynamic relationship to enable sectors to identify critical AM requirements, feeding these into thematic groups and exchanging knowledge
- Encourage thematic workgroups to engage with university research agendas and national and international innovation priorities, to maximise knowledge transfer
- Support thematic groups to identify actions required to address critical challenges and recommend what and how the priority actions should be implemented
- Manage the scope and lifecycle of the thematic groups according to need
- Investigate needs, solutions and options to establish a national point of focus for AM
- Develop and implement a national AM Awareness Programme
- Promote Additive Manufacturing UK and its implementation programmes to all key stakeholders including industry sectors, professional bodies, local and national government
- Encourage sector bodies to take full account of Additive Manufacturing UK in their respective industry strategies, roadmaps and plans
- Take opportunities to align more closely with any government initiatives regarding a National Innovation Plan and Digital Strategy
- Co-ordinate and integrate Additive Manufacturing UK as a key part of the government's new industrial strategy, which is part of the renamed Department for Business
- Identify the range of skills needed to define the curriculum for AM, and use this to structure the required skills development and training programmes
- Develop and promote mechanisms that deploy apprentices and technicians into industry with AM technology training, in order to expand our productive industrial capacity more effectively
- Develop and publish a final strategy over the next 6-12 months
- Conduct major review of the strategy for its relevance and impact every two years.

What we will achieve

Co-ordination and communication

- Establish a National Point of Focus for AM
- Start a UK Awareness Programme
- Define major gaps and common problems across sectors.

Invest in UK capacity

- Identify geographical 'hot-spots' for opportunities
- Have in place a known route to major lenders to improve financing of AM
- Investment conference.

Strengthen the industry sectors

- Have sector champions in place
- Have sector representatives in all thematic Groups
- Identify gaps and problems related to specific sectors
- Generate sector input into the Awareness Programme
- Develop an AM Economic Growth Plan for each sector

Measure progress

- Method for forecasting AM growth
- A forecast for AM in all UK sectors

Developing the knowledge and skills

- Develop a standard for an AM apprenticeship
- Develop a general approach to AM training in conjunction with the sectors
- Produce a Skills/Training Plan (including numbers, types of skills, different levels such as on the job, apprentices, colleges, universities)

Recommendations

What the UK must do to create an AM economy

To capitalise on UK strengths in AM and ensure successful delivery of the five programme framework covering; co-ordination, sector strengthening, skills development, capacity investment and measuring the economic impacts, the following recommendations are made:

1. Sector Councils and Leadership Groups should embed Additive Manufacturing in their strategies and identify the business opportunities and barriers related to AM. Co-ordination with the relevant cross-sector activities is also necessary
2. Trade Associations and other institutions involved with the industrialisation of advanced manufacturing technologies should consider the impact of this framework on their areas of expertise and interest, and liaise with the Strategy Steering Group to identify areas for joint or co-ordinated activity
3. Local Enterprise Partnerships and City Regions should use this framework to support and accelerate industrial exploitation and to position AM as part of their smart specialisation strategy. Local business support programmes should be cognisant of the opportunity presented by AM
4. Government to ensure that it aligns its policies and programmes with the strategic needs of AM industrialisation
5. Public and private sector skills and education providers need to deliver sufficiently trained people to ensure the industrialisation of AM is not held back by workforce shortages. This will involve delivery of high quality, multi-disciplinary education and provide learning at all ages, including through part-time study and workplace training.
6. Industry should work together to design appropriate apprenticeship standards and assessment approaches for additive manufacturing
7. Standards setting bodies should engage with industrial sectors regarding the development of AM standards
8. UKTI should embed AM within their strategy regarding inward investment and increasing exports
9. Future funding support for Research and Innovation in AM is required to support the priority needs identified by industry
10. A single point of focus such as an association for Additive Manufacturing should be explored by industry and trade associations. A key role would be to raise and maintain awareness, boost adoption, drive collaboration and technology transfer, and improve UK competitiveness.

An AM strategy for the UK

The Steering Group's objective is to see the UK achieve the £5bn opportunity by being a leader in AM technology development and exploitation. The Steering Group wants to engage and co-ordinate with government and organisations that support UK industry and companies in all sectors to align and promote AM activities, to capture investment in capability development and to support research and innovation in the delivery of industry led solutions. We believe that the correct co-ordination will enable a highly efficient AM ecosystem where UK industry has the best opportunity to profit from this technology.

The AM Strategy will move the UK from a set of short term recommendations to be addressed over the next year, to a set of long term requirements and associated delivery roadmap to enable us to meet the targets for 2025. It will also detail what help we need, and from whom, to achieve this. It is expected to contain:

- Summary of outputs to date from the thematic workgroups and associated recommendations
- Updated overall recommendations list based on the work completed from Sept 2016 to Mar 2017 and associated new findings
- Roadmap to deliver the agreed recommendations from 2017 to 2025, showing main delivery points and activities
- Explanation of what we need and whose help we need to enable delivery of the above roadmap
- Governance structure for monitoring progress – who will be involved, frequency, reporting
- Timeline for wider external updates on progress
- Delivery of the Single Point of Contact with the report detailing its purpose and how this will advance the Strategy.

The Steering Group intends to publish a UK AM Strategy in April 2017 and would like to invite any organisations wishing to contribute to contact a member of the Steering Group whose names are listed in Appendix One, or to the programme management team on 02476 647389, by 1st December 2016.

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Appendix One

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

Neil Mantle	Rolls-Royce (Chair)
Robert Scudamore	TWI (Deputy Chair)
Rob Sharman	GKN
Clive Martell	Renishaw
Simon Locke	Dyson
Clare Marett	Department of Business, Energy and Industrial Strategy
Julian Mann	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, University of 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, HP Enterprises
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

From time to time the Steering Group had assistance from others not mentioned above, this has been greatly appreciated.

Acknowledgements

This document has been prepared by members of the Steering Group with particular contributions by Prof. Phill Dickens of the University of Nottingham, Prof. David Wimpenny of the High Value Manufacturing Catapult at the Manufacturing Technology Centre, Ian Collier of the High Value Manufacturing Catapult and Robin Wilson of Innovate UK. The UK AM Strategy Steering Group would like to thank all those who contributed to this strategy, and the development of its implementation plan, including the representatives from industry, academia and professional organisations who have enabled us to pilot the thematic workgroups.

We are grateful to Stratasys Strategic Consulting (UK) for use of the table in Appendix Two and to Wohlers Associates for the market growth chart.

We are also grateful to members of the Composites Leadership Forum for their guidance and wisdom in the early days of this strategy's development.

Appendix Two

The seven categories of AM technologies

Classification	Material	Process Description
Powder Bed Fusion	Metal	Selective Laser Melting (SLM) Electron Beam Melting (EBM)
	Polymer	Selective Laser Sintering (SLS) Masked Sintering Infrared Sintering
	Ceramic	Laser Sintering
Directed Energy Deposition	Metal (powder feed)	Laser Metal Deposition (LMD) Plasma Deposition
	Metal (wire feed)	Electron Beam Direct Melting Wire Arc
Material Jetting	Photopolymer	Photopolymer Ink-Jetting
	Wax	Wax Ink-Jetting
	Organic	Organic Ink-Jetting
	Metal	Liquid Metal Jetting

Classification	Material	Process Description
Binder Jetting	Metal	Metallic Binder Jetting
	Ceramic	Gypsum Binder Jetting Ceramic Binder Jetting Sand Binder Jetting
	Polymer	Polymer Binder Jetting
Material Extrusion	Polymer	Extrusion Co-Extrusion
	Ceramic	Extrusion Paste Extrusions
	Organic	Extrusion
VAT Photopolymeri-ation	Photopolymer (Ceramic)	Ceramic Loaded Stereolithography
	Photopolymer	Sterolithography (SLA) Digital Light Processing (DLP) Two Photon Lithography (2PL)
Sheet Lamination	Metallic	Ultrasonic Consolidation
	Ceramic	Laminated Object Manufacture
	Organic	Adhesive Lamination

Appendix Three

List of economic sector families in AM strategy (related to analysis of SIC codes)

Sector Family	SICs	SIC description summary
Aerospace & space	30300, 33160	Manufacture, repair and maintenance of air, spacecraft and related machinery
Automotive	29100, 29200, 29310, 29320, 45200	Manufacture, maintenance and repair of motor vehicles, trailers, caravans, electrical and electronic equipment for motor vehicles
Business services	62012, 62020, 63110, 63990, 71120, 72190, 74100	Software development, IT consultancy, data processing, legal activities, business consultancy, technical testing and services, other R&D on natural sciences & engineering, specialised design services
Construction	41200, 42130	Construction of commercial & domestic buildings, bridges and tunnels
Consumer goods	15200, 23410, 27510, 32120, 32200, 95220, 95240, 95250	Manufacture and repair of footware, ornamental articles, domestic appliances, jewellery, musical instruments, sports goods, professional and other games & toys, home and garden equipment
Defence	25400, 30400	Manufacture of weapons, ammunition and military fighting vehicles
Education	85310, 85320, 85410	General secondary, technical, vocational, tertiary education and support services
Food and drink	10710, 10821, 10860	Manufacture of foods and drinks
General industrial	18129, 20160, 20302, 22290, 23440, 25110	Printing, manufacture of plastics, paints, technical, ceramic, metal structures and components

Sector Family	SICs	SIC description summary
Health and pharma	21200, 32500, 75000	Manufacture of pharmaceutical preparations, medical and dental instruments and supplies, veterinary activities
Machinery and equipment	25730, 26510, 27110, 28110, 28240, 28490, 33120, 33190, 33200	Manufacture and repair of tools, electronic equipment, electric motors, pumps and compressors, taps and valves, hand tools, metal forming machines, special purpose machinery, cooling and ventilation equipment
Transport	30110, 30200, 30910, 33150, 33170	Manufacture, building and repair of railway locomotives and rolling stock, motorcycles, bicycles, invalid carriages, ships, pleasure boats, other floating structures

* Standard Industrial Codes (SIC) shown above are not exclusive

Appendix three continued

Sector	Sector Size (2012 BIS figures)		Estimated AM impact in 2025		Value creation mechanisms
	GVA	Employ't	GVA	Employ't	
Machinery & General Equipment	£269b	7,350,000	£1,800m	46,000	AM equipment development - whole production chain. Systems integration and novel manufacturing processes
ICT / Precision Instruments	£70b	1,300,000	£1,600m	23,000	Systems integration, novel architectures, innovative digital solutions ref AM
Construction	£92b	2,000,000	£875m	15,000	Design, weight and energy efficiency. Enable cost effective one-off and customised methods
Aerospace	£6b	112,000	£325m	5,000	Innovative products at component and system levels - increased functionality at requisite scale of production to airworthiness standards
Pharmaceuticals	£10b	38,000	£165m	450	New and innovative customised patient level solutions. New product development and reduced healthcare cost base through device life extensions
Automotive	£7b	133,000	£250m	3,500	Prototyping and customisation, innovative powerplant and transmission products standards
Defence	£68b	1,650,000	£90m	1,600	Bespoke military solutions made available to support UK export market
Process Industries	£73b	1,100,000	£140m	1,100	System level product innovations
Education	£90b	2,700,000	£110m	2,500	New teaching methods and equipment with broad syllabus impact
Utilities and Shipbuilding	£39b	350,000	£100m	750	Innovative products and management of customised spare part inventories and development of maintenance and repair solutions

Note 1 - Estimated AM sector growth shown relevant for the UK with a strategy adopted
Note 2 - Employment impact is estimated new AM related jobs for given growth

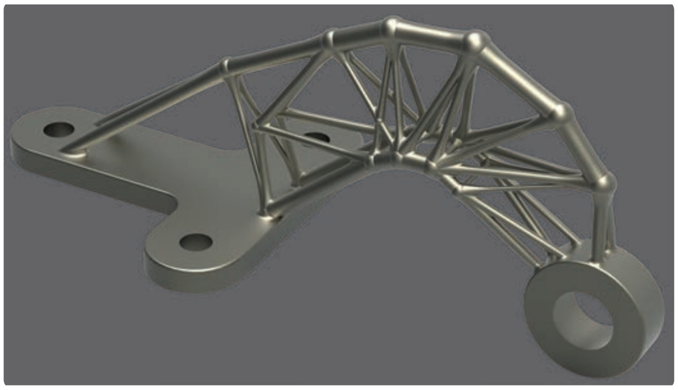

Image courtesy of Limistate and the Innovate UK funded ANVIL project