

POSITIONING PAPER:

The Case for Additive Manufacturing

March 2015

EXECUTIVE SUMMARY

Additive Manufacturing (AM) is a key enabler in high value manufacturing where benefits, such as smarter supply chains, digital manufacturing flexibility and design freedoms, will produce a paradigm shift in the way components are designed, developed, manufactured and supplied. The worldwide AM market forecast is £67 billion by 2020, if the technological and commercial barriers are overcome [8]. It is estimated that this could be worth £5.7 billion in market share and over 63,000 jobs sustained for the UK by 2020. AM technologies will also underpin the High Value Manufacturing Sector which is currently worth £151 billion, and sustaining 1.6 million jobs [1,2].

AM is a true cross-sectorial technology with high value sectors involving Aerospace, Medical, Automotive, and Consumer Products. However, applications can be found across a wide range of sectors. AM technology has the potential to enable creation of novel products, new markets, and innovative business models to be exploited.

The UK is amongst the global leaders in both the development of knowledge and successful application of AM technology. However, there are gaps in the supply chain (materials supply, equipment, post processing and validation). Therefore, industry leaders and initiatives, such as the Foresight Report [5], are recommending the urgent development of a UK National Strategy on AM.

The UK is currently well placed to take advantage of AM, however, national strategies around the world will raise the base level of competition and provide those nations with a significant advantage as they co-ordinate and focus their research, innovation and commercialisation activities.

Government involvement is needed to address market failures, and help coordinate a fragmented AM community to develop approaches, particularly top-down, to overcome barriers to exploitation of the technology.

The identified market failings, including imperfect information and uncertainty, need to be addressed to prevent a lack of confidence in current and future capabilities of AM technology. This will encourage and enable business investment. There are skills needs where it is currently impossible to bring together all the different sectors to clearly state what those needs are, resulting in an unknown UK demand.

A robust supply chain which encompasses all of the critical elements for AM to flourish in the UK needs to be secured. Access to finance is also an issue for many businesses who wish to adopt AM.

Some of the market failings may in time be partially solved if left to market forces. However, Government can play a fundamental role in accelerating the process, in a coordinated way, to ensure that UK companies can remain ahead of international competition.

This paper examines three alternative scenarios for intervention and concludes that the only robust and sustainable approach to address these market failures and ensure maximum economic benefit from this new technology is to develop a Government supported UK Strategy for rapid, high value industrialisation of AM.

It is therefore recommended that Government engages with the already ongoing effort by Industry and Research to develop a UK National Strategy in AM. This will involve allocation of resources and direct involvement. The strategy development process will provide recommendations for investment. It is therefore, requested that Government seriously consider these recommendations.

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1 The Case for a UK National Strategy on Additive Manufacturing

The evidence presented in this document places the UK amongst the global leaders in knowledge and successful application of Additive Manufacturing (AM), also known as 3D Printing. This disruptive technology has the potential to transform how and where manufacturing is done across a wide range of industrial sectors and global markets. Moving from mass production to mass customisation, from large capital intensive factories to smaller, local centres of design and production excellence. AM will significantly shape the future of manufacturing towards a more flexible and on-demand approach, involving integrated systems, as outlined in strategies such as Germany's Industrie 4.0.

The AM market in the UK has the potential to reach £5.7 billion in market share, and sustain more than 63,000 jobs by 2020. AM technologies will also underpin the High Value Manufacturing Sector which is currently worth £151 billion, and sustaining 1.6 million jobs. This is based on a National Strategy that increases the current UK market share to 8.6%, where number of installed machines is proportional to overall market value [1,2]. Our evidence points to now as the right time for the UK to build on its strengths, address its critical needs, and harness its collective capability to deliver the competitive advantage which this technology has to offer us. In terms of its significance to Government, the evidence indicates that AM is already starting to shape the strategic thinking of a number of major UK companies, and as such could soon influence the UK Industrial Strategy. At the same time, recognising that the term Additive Manufacturing, also called 3D Printing, is actually a family of 7 very different processes [3], and its potential to transform a whole range of today's established production methods makes it a contender to be positioned alongside the Eight Great Technologies [4].

As a first step, it is recommended that a UK Strategy for AM is developed, to bring together the key activities in research and development, the multi-disciplinary skills provision, and the industrial capacity development. This will optimise public and private investment and achieve a better alignment and focus of the limited UK resources. Beyond the strategy development, its implementation for maximum impact and competitive advantage would require a programme approach, and high level leadership to ensure the co-ordination of significant investment, both from private and public sources, over the next five years and beyond.

The remainder of this paper sets out to make the case for taking this first step; the development of a National Strategy for AM.

AM is a key enabler in high value manufacturing and the design aspects in particular will produce a paradigm shift in the way components are designed, developed, manufactured and supplied. AM has seen significant double digit growth in recent years and this is forecasted to continue, in spite of technical and commercial barriers which need to be addressed. AM presents complex, multi-disciplinary challenges where the benefits can be at any stage of the development cycle, and can result in changes in business models drastically affecting the make-up of supply chains and opening up new markets.

In its Manufacturing Foresight Report 2013, the Government Office for Science gave a comprehensive vision for "a new era of opportunity and challenge for the UK" and made a number of recommendations, including the need for "increased effort in key areas such as sensors and AM, to develop technology roadmaps and to guide policy" [5]. It advised that "Advances in technologies such as AM will digitise manufacturing. It will take place closer to the customer, with a much greater range of products becoming more personalised and tailored to specific needs. Factories of the future will be more diverse in their scale, with potential for mobile and home manufacturing.

Government will need to ensure that UK manufacturers are able to take advantage of the technological revolution in how products are designed, made, offered, used and recycled. In particular, there is a strong case for better overall coordination of the technology pipeline for manufacturing technology”.

In a letter sent to Matthew Hancock in October 2014, the leaders of ten leading UK and International companies highlighted the importance of AM to the UK’s future prosperity, and made the case for a National Strategy and Leadership Group supported by Government. Significantly, this was not just from a group of companies representing one industry sector, they covered a wide range of interests including medical, pharmaceutical, aerospace, consumer goods, packaging, automotive, machine tools and design. The letter states that “not only is AM an emerging technology, but it is also a very powerful cross-cutting technology and impacts at least 9 of the 11 main industrial sectors highlighted in the strategy”, referring to a short analysis in support of the letter, provided by Innovate UK, see Table 1.

Table 1: Expected impact of AM on the 11 main sectors identified in the UK Government's Industrial Strategy (Analysis by Robin Wilson, Innovate UK. October 2014).

No.	Industrial Sector	AM Impact
1	Aerospace	Yes
2	Agricultural Technology	No/Unknown
3	Automotive	Yes
4	Construction	Yes
5	Information Economy	Yes
6	International Education	No/Unknown
7	Life Sciences	Yes
8	Nuclear	Yes
9	Offshore Wind	Yes
10	Oil and Gas	Yes
11	Professional and Business Services	Yes

The ten leaders of industry go on to say “The objective now is to build on our strengths in AM research and innovation, and focus our future efforts more closely on becoming a world leader in its multi-sector adoption and use”.

The UK is currently well placed to take advantage of AM, however, national strategies around the world, including in the US, China and Singapore, will raise the base level of competition, and give those nations a significant advantage as they co-ordinate and focus their respective capabilities and marketing efforts. There is a danger that the UK, despite being a world leader in AM knowledge and application, will not effectively exploit this technology, thus seriously reducing the UK’s competitiveness in the field of high value manufacturing. UK capabilities, in many areas, are fragmented and the connections between exploitation efforts are tenuous.

The UK would, therefore, benefit from a national strategy on AM that would define and explore the AM landscape, identify gaps in capability whether they be isolated or interconnected, evaluate the UK’s capability to address these opportunities, and put a plan in place to deliver an enhanced and integrated UK AM competence. This competence would focus on the-state-of-the-art, but it is also key that the accessibility of AM to industry is optimised. The main vision and focus for the UK National AM Strategy would be on end-product exploitation, however, all benefits along the value chain should be considered, including business models and equipment supply. Education and skills is a key area, inspiring the next generation of UK designers, engineers and scientists to embrace AM is fundamental for long term sustainability.

Currently there are market failings in the following areas:

Technology Awareness – Companies need to be familiar with what the technology can do currently and what is likely to be available in the near future. Some of this raising of awareness is happening, but there is a confusion of information coming from the market. There needs to be a realistic awareness campaign, which disseminates reliable information to industry. Without Government coordination this will not happen, and many companies will get either no information, or worse, misleading information. This will lead to inappropriate investment or will delay decisions, leaving UK companies at a disadvantage compared to their international competitors.

Skills – Without government coordination it will be impossible to bring together all the different sectors to clearly state their skills needs and so the UK demand will not be known. Therefore, the UK will not be in a position where it can plan how to meet those needs.

Education – There is AM education occurring now, but it is patchy and uncoordinated. Government should use its influence on the education sector to enhance this provision.

Supply chain failure – It is important that companies in the UK can access a robust supply chain which encompasses all of the elements which are critical for the reliable exploitation of AM technology. The UK is largely dependent on overseas suppliers of machines. Government should consider whether this is a market failing it needs to address. Similar to machine supply, this area is dominated by overseas players. There are also limited amounts of suppliers that truly have an understanding of the requirements of AM. Government could encourage more UK companies to be involved in the supply of AM materials.

Access to finance – Many finance companies are looking to invest in AM while many companies find it difficult to access finance. Government could encourage an activity that brought together these two groups. AM should be seen as a method of reducing risk through manufacturing competitiveness, rather than increasing it due to uncertainty around the techniques.

Support to businesses in adopting AM – This will bring together a broad range of expertise, so that businesses can get the right advice and support in order to achieve their full potential. This could be supported through use of the Business Growth Service (formerly MAS) and the Catapults. This is what is being considered for Industrie 4.0.

Clustering – There may be significant benefits from encouraging clusters of AM companies, for example around Research and Technology Organisations, such as the Manufacturing Technology Centre, a University, or a major AM user like GKN or Rolls-Royce. This will provide a critical mass for supply chain development as well as addressing information asymmetries which limit the connection between businesses and knowledge producing organisations.

Some of the areas above might be partially solved if left to market forces. The main problem is that by the time a solution has been created by leaving it to the market; other global players will have a significant lead. The fundamental role Government can play is accelerating the process, in a coordinated way, so it is UK companies that are ahead of the international competition.

The Strategy Development Group is currently moving forward with the drafting of the UK National AM Strategy. Initial contact with industry was overwhelmingly positive, as is evidenced from the support for this document. The strategy development will be in two phases. This document represents the first phase of work, providing an initial scoping and case for the strategy. Phase 2 will develop the evidence further, canvassing industry for

information on their chosen route to AM exploitation, and what they see as the challenges and opportunities. Phase 1 will be presented to Government in March 2015.

Phase two is in the planning stage, keeping in mind the industrial need for urgency. Government is encouraged to endorse and engage with Phase 2. The proposed UK National AM Strategy will result in major benefits to UK industry but, with Government support, will be much more coordinated, and hence will deliver greater impact. The industrial feedback has emphasised the need for urgency, because AM is a fast moving field, and the opportunity for the UK to benefit from early adoption will reduce with time.

Stepping back from the current activity to view the options in the context of UK Industrial Strategy, there are three approaches that could be taken regarding the industrial exploitation of AM:

Scenario 1: Do nothing

Expected consequence: With no unifying strategy and only today's very informal network of expert users, market forces would result in the dominance of overseas companies providing the equipment, materials and support services into the UK, in a matter of only 3-5 years' time. UK-based large, multinational AM-user companies in Aerospace, Pharmaceuticals and other major sectors would in the same timeframe have decided to locate their new investments in AM production capacity in overseas territories, to be close to sources of critically important technical expertise and support services. The UK would therefore see limited exploitation and little economic benefit from this technology. Any residual clusters of expertise would also rapidly become very fragmented. Many existing manufacturing companies would remain unaware of AM, or see it as too high risk to consider. Where AM displaces current methods, those more traditional manufacturing companies would soon suffer rapidly diminishing demand, having been deprived of the necessary information and support to enable transition to the new AM-based solutions.

Scenario 2: Industry and Research develop a strategy not involving Government

This approach would identify the issues, but would not be able to develop a joined-up response that would address the market failures and reduce risk. Fragmentation of effort would continue to be an issue. At the time of preparing this paper, an informal group of AM experts drawn from industry and academia have made a start at developing a UK Strategy for AM, with its first stakeholder workshop planned in March. This was done in response to the expressions of urgency made by the industrial members of the working group, who made it very clear that the pace of progress in development and adoption of AM by their competition around the world had rapidly accelerated in the last six months, putting the UK at increased risk of being left behind. Without the support and engagement of Government, this approach will inevitably have very limited reach and impact. Industry and the Research Community can provide the bottom-up elements of the strategy, but Government is fundamental to the top-down elements, for example, through engagement with the Sector Councils.

Scenario 3: National AM Strategy supported by Industry, Government and supporting organisations

This would allow a coordinated effort that would draw the community together, give a greater sense of purpose, address the market failures and other challenges, and reduce the risk of AM adoption for industry.

This 3rd option would give all the benefits of the second option above and would also enable us to align and co-ordinate at National level the key activities and public funded resources. This would include research agendas, innovation and Catapult priorities, Intellectual Property Office support, UK Trade and Industry engagement, skills and supply chain development, plus local and regional growth initiatives.

2 Background and Importance of Additive Manufacturing

The term Additive Manufacturing (AM), also known as 3D printing, is used to describe a technique in which components are built in layers direct from digital data, without the need for dedicated tooling and all the associated investment costs. Companies have been using this technique in the UK since the late 80's/early 90's for the production of prototypes to aid product development. In the 1990's the UK became one of the leading countries in using this technology within the product development arena. In 1996 the first serious work to investigate the possibility of using the technique as a process to make production parts was instigated in the UK in association with Flymo Ltd. However, due to limitations in material properties and production speed it has, until recently, remained largely as a prototyping technique.

AM has the potential to drastically transform manufacturing norms, particularly for high value application areas including Aerospace, Automotive, Medical, and Customised Consumer products. This is because AM, as a cross-cutting technology, offers an array of distinct advantages over more conventional processing. For example, owing to the design freedom, near 100% material utilisation and short lead times, AM enables unrivalled customisation for performance, whilst minimising waste. This applies in many sectors but is particularly important for the Aerospace sector in optimising airframe and engine functionality, whilst reducing cost and waste. Figure 1 shows an example of an aerospace component with optimised topology made by using AM for the purposes of cost and weight saving, and minimising waste.

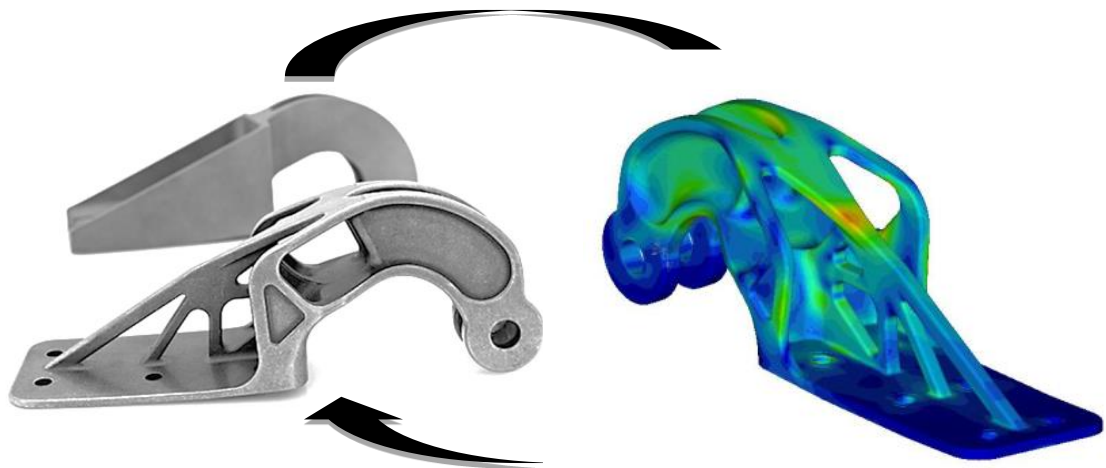


Figure 1: Aerospace titanium bracket with optimised topology made by using AM technology. Project partly funded by Innovate UK (Images courtesy of Airbus Group) [6].

The following was taken from a statement by **Hamid G Mughal, Director of Global Manufacturing Rolls-Royce Plc:**

“On a like for like basis we have already demonstrated a 30% reduction in component manufacturing lead time and the added flexibility of this digitally enabled technology is making design iterations faster and more cost effective. The industry focus now must turn to industrialisation of the process and the establishment of capable supply chains if we are to harness the full potential of ALM.”

In the Medical sector, AM can also enable accurate patient specific implants to be created using the patient's CT or MRI scan data, increasing implant life for an ageing population. **GlaxoSmithKline Research & Development** want to take their AM research further and are exploring the use of AM in the production of oral solid dosage (OSD) products (tablets and capsules). This involves using cartridge-based printing machines, distributed near patients in local pharmacies or hospitals, and is envisioned as a potential model for providing patients with medicines customised for their specific care needs.

In addition to its considerable potential in high value sectors, AM is seen as playing a very significant and pervasive role in enabling a whole new way of designing and making things in the world of customised consumer products. For example, artists, jewellers and fashion designers are using AM in a range of ways to make one off bespoke pieces [7].

In a statement from the design consultancy **Sebastian Conran Associates**, **Sebastian Conran** states:

“Leading global businesses use the best design to keep them ahead of the game by innovating, which leads to differentiation and market growth. This is attained by using the right design expertise and technology at the right time, especially in the early stages of the innovation cycle. AM not only speeds up this process by allowing rapid prototyping, but also allows us to fabricate things that previously would not be possible due to cost of tooling and technical limitations of traditional solutions. As a consequence an entirely new generation of fabrication techniques are now becoming available to the designer who wishes to harness other emerging technologies to innovate resilient and satisfying consumer experiences”.

The technology holds a powerful economic capability of enabling localised manufacturing. For example, there is no expensive tooling required and such advantages have allowed early adoption by many companies, particularly SME's, which have contributed significantly to economic growth and brought outsourced jobs back to the higher wage rate economies. AM is also being used as an alternative method, for example to replace wasteful subtractive processes, but also to unlock new business models and new markets. Hence, the effects of AM on supply chains will range from subtle to wide reaching.

Conventional manufacturing methods routinely centre on processes such as weld fabrication, casting, forging and machining. AM however, requires a completely different material feedstock preparation, the equipment used in AM is completely different to conventional processes, and the challenges in achieving part compliance are often unique to AM. These issues and other challenges contribute to AM having a disruptive influence on Supply Chains that seek to unlock the potential for more localised manufacturing using this flexible, on-demand, approach. The reduction of the necessity for part inventory with the possibility of 'print only location' is another advantage that promotes the use of AM. The level of automation involved, the potential for 'lights out' AM factories, will allow the UK to be more competitive on the world stage.

Not only is AM a fast emerging technology, it is gaining momentum as one of the most prominent enabling technologies, across a wide range of industrial sectors, with the greatest potential for streamlining the supply chain and significantly impacting the value added activities of manufacturing products [7,8,1].

3 Growth of the Additive Manufacturing Market

In 2013 the global market value for revenue generated by AM products and services stood at over £2 billion. At the moment this is mostly associated with the production of prototypes for product development with a small proportion for end use parts. However, manufacturing is expected to be the main growth area. Since 2010 the industry has seen significant double digit growth year on year, and by 2016 the market is estimated to be over £5 billion [1,7]. However, if current technological and commercial barriers can be removed, the AM market value could progress to be worth in excess of £67 billion by 2020 [1,8].

In terms of worldwide revenue generated from materials for AM, in 2013 metals were estimated at approximately £22 million, with laser sintered polymers at £90 million, over £67 million of which was generated outside the US. Photopolymers represented the most with a total reaching £152.6 million in revenue for 2013. Although, metals and plastic are the main materials used in AM, there are many other materials coming into use such as ceramics, conventional composites and hybrids [1].

The average selling price of a professional AM system in 2013 was £60k compared to £49k in 2011. These figures do not include estimates for smaller systems such as 3D printers. Of particular interest in AM machine sales is a regional dominance shift reported by Wohlers. In 2012, the US was the market leader by producing 61% of all industrial systems with the likes of Stratasys, Z Corp, 3D Systems and Solidscape leading the way. Recent changes have now seen Israel, through Objet, representing 54.7% and the US a mere 18.6% for 2013. However, when looking at the cumulative figures for machine sales since 1988, US manufactures still dominate [1].

Looking at more local economics, Europe seems to be gaining some momentum with a growing position in machine sales standing at 21% in 2013. This is predominantly in the area of metal component production where Europe has a dominant position [1].

Sir David R McMurtry, the Chairman and Chief Executive of a UK AM system manufacturer, **Renishaw Plc** stated:

“The AM market represents a huge opportunity for Renishaw and other companies involved in the supply of machinery, materials, software and other ancillary equipment. Renishaw are seeing strong growth in the interest in metal AM part manufacture from key industry sectors such as aerospace and automotive, all attracted by the ability to produce ‘smart’ products exhibiting benefits such as lighter weight and increased performance well beyond the capabilities of conventionally machined or moulded parts. However, this is a market very much in its infancy and Renishaw estimate that under 1% of market potential is currently being met by metal-based AM technologies”.

Where industrial machine installations are concerned, North America is the largest adopter occupying nearly 40% of the world’s total. Europe occupies 30% with Asia and the Pacific occupying just over 26%. Within Europe, Germany is the dominant player for machine installations at 9.1% with the UK following at 4.3% [1].

In terms of industrial applications, a number of sectors have already established themselves for the production of direct part production using AM technologies. For example, a survey of 29 AM system manufacturers and 82 service providers worldwide ascertaining which industries they served and their approximate revenues was conducted by Wohlers Associates Inc [1]. The survey revealed industrial and business machines as the leading sector for using AM technologies. This is shortly followed by consumer products and electronics, then motor vehicles with medical, dental and aerospace sectors also being great users of AM technologies, see Figure 2. Most of this was for prototyping but indicates industry activity. The survey also revealed how their customers are using parts built by their AM systems. Functional prototypes represented the highest percentage (29%) with fit and assembly representing the second highest with 19.5% [1].

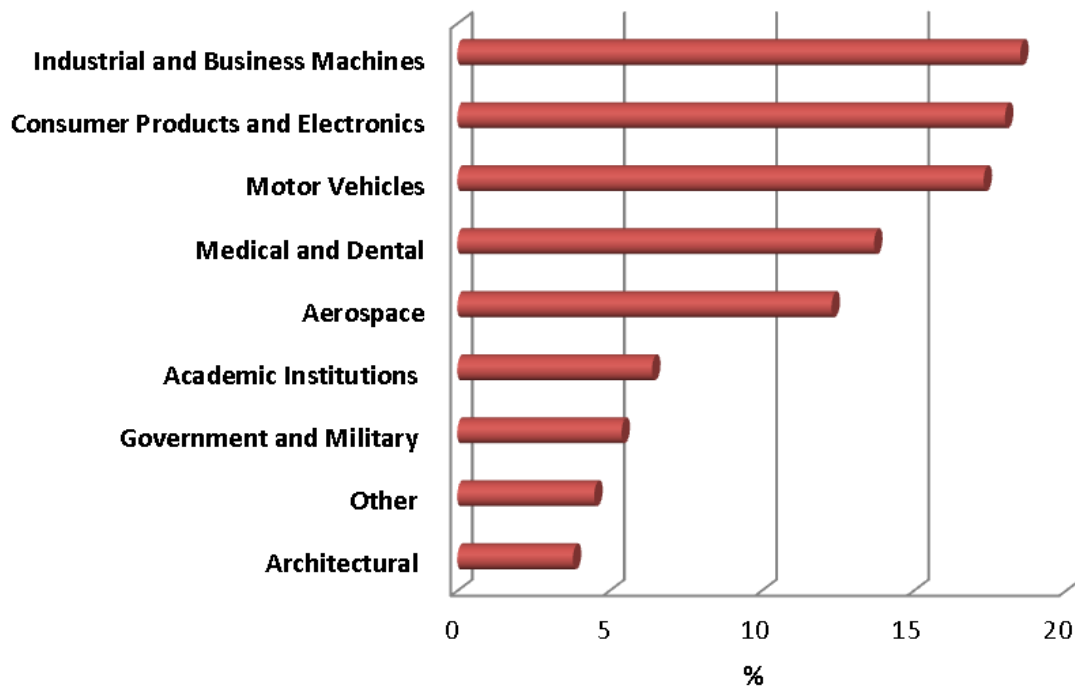


Figure 2: Breakdown of sectors using AM and revenue generated in terms of percentage.

In another statement from **Sir David R McMurtry** he stated:

“Renishaw are particularly interested in the healthcare area and are encouraged by the global prospects for AM. They are already working on pilot projects with UK partners in areas such as dentistry and maxillofacial surgery, but stated a need for further investment to be able to commercially exploit highly promising research at a pace that will enable the UK to gain early mover advantages. The global market for digital dentistry, for example, is forecast to grow strongly due to faster adoption rates of digitally-based manufacturing processes”.

4 Emerging Global Strategies

The strong growth in AM and the increasing awareness across others sectors is driving economies to act and move faster by increasing not only their support through investment in research and commercial development, but some are also starting to develop strategies based around this promising technology. These are at various but early stages of development and include USA, China, South Korea, Canada, Singapore and UAE. For instance, the US based initiative 'America Makes' is attempting to mainstream AM within industry to boost manufacturing within the US. The initiative brings together a network of researchers and industry with the aim of building a national presence for AM. They are reporting almost £6 million in public investment and £10 million from industry. In early 2014 the federal government announced an increase in funding commitment to £33 million. The US sees AM impacting in the areas of defence, energy, aerospace, medical and commercial applications. In October 2014 the US Government Office for Accountability held a 2-day workshop to try and develop a national strategy for AM [1,9].

A number of reports show investment plans for the technology from a range of Asian countries. For instance Chausovsky of IHS reports Japan allocating nearly £26.6 million for national 3D printing projects with 80% focusing efforts on research and development of metal end use products [10]. Japan is also launching, with a number of noteworthy industrials (Nissan, Panasonic and Mitsubishi), universities and institutes, a research and development initiative investigating 3D printers for producing high end metal parts. Chausovsky also reports China and South Korea making similar investment strategies targeting the 3D printing industry [10].

In September 2014, the South Korean government set up a development-direction policy forum. The aim of the event was to make policy makers aware of how they can support developments in the 3D printing industry by removing governmental bureaucratic barriers. Emphasis played on large scale industrial applications, but also looked to support programmes for SMEs [11].

In China the government are concerned about the potential of the technology to undermine the competitive advantage they have made in manufacturing. A new report reveals that China will aim to fully embrace the AM technology and have plans to increase its sales of printers four-fold by 2018 in order to more than triple its revenues to £73 million. Although this may seem modest, the rapidly growing adoption of the technology and notable government policy support aiming for China to be a future leader in this emerging technology will boost annual growth significantly [12].

Last year in Singapore, the government announced its plans for investing in advanced manufacturing technologies to the tune of approximately £267 million. This investment is part of a program aimed at manufacturers to engage their further involvement in emerging technology in order to increase the countries competitiveness. As part of the investment plans, a new £20 million research centre focussed on AM has been announced by Nanyang Technological University [1].

This is just a select few of the global developments taking place. Particular attention must be drawn to fact that AM/3D Printing has the potential to deplete sections of a country's more traditional manufacturing base, particularly if AM is not fully adopted and subsequently exploited to gain competitive advantage. This paradigm shift in manufacturing has been developed through the ability of AM technologies to offer design flexibility, optimised material utilisation and shorter lead times.

Emerging National Strategies are designed to yield both short and longer term advantages to the countries that develop and implement them, resulting in faster adoption and economic benefits from these disruptive new technologies, at the same time driving aggressive, better focused R&D agendas securing vital know-how to protect their future competitiveness. Such initiatives pose a very real threat to other economies, forcing them to lose out to the pro-active companies and nations which have taken the lead.

Sir James Dyson – Chairman, Dyson Limited

“Dyson uses 3D printing extensively for building test rigs and prototypes at all stages of product development. We have been actively following the recent improvements in materials, resolution, speed, and cost reduction that will allow production-scale additive manufacturing techniques to take off rapidly in the next few years and be an important and flexible part of the manufacturing environment. We are most interested in the opportunities enabled by high quality additive manufacturing, as it relates to parts manufacturing and distribution in territories we operate in as a global company, and the opportunities it offers for customisable mass production.”

5 UK Capacity

AM is a rapidly growing technology and the UK is well placed to develop as a world leader in the industrial application of AM. The relevance of the UK dominant industry sectors, and its strong position in AM process development, provides the UK with an opportunity to gain advantage over competing economies. The UK Industrial Strategy identifies Emerging Technologies as one of the 5 key themes where Government support can have real impact [13]. Not only is AM an emerging technology, but it is also a very powerful cross-cutting technology and impacts at least 9 of the 11 main industrial sectors highlighted in the strategy. AM is also identified by Innovate UK in their High Value Manufacturing Strategy as one of the key manufacturing competencies in which the UK is well placed to invest for strong future growth [13].

The UK has considerable capacity in research and is one of the world’s leading sources of AM related knowledge and research activity, with 81 organisations being involved in AM research since 2007 (including 24 universities and 57 companies). Within the UK, EPSRC funds a Centre for Innovative Manufacturing in AM and a Centre for Doctoral Training in Additive Manufacturing as well as a number of individual projects. There is also the National AM Centre located at the Manufacturing Technology Centre.

The AM Specialist Interest Group (SIG), led by the Materials Knowledge Transfer Network (KTN) and supported by Econolyst Ltd, has identified a large range of current and potential AM applications and development within UK manufacturing. Research suggests that all sectors are interested in the use of AM for both “cloned” part manufacture and “freedom of design” part manufacture. Significant public and private sector investment (circa £90 million) has been made or committed within the UK in recent years to drive up the Technology Readiness Level (TRL) of AM. This funding has established the UK as a leading location for AM R&D activity across the value chain. The aerospace, healthcare, creative industries and motor sport sectors have examples of products under development being tested in niche applications or being sold on a small scale [8].

The UK also has the potential to build a strong knowledge-based AM supply chain with the presence of enabling software companies, materials providers developing innovative

product offerings, and world class product designers with a strong interest in AM. When this is coupled with the strong multi-sector interest by world class OEMs and end-users, the UK is well positioned to realise the high value industrial potential of AM technologies. The UK has a strong research base focused on the following AM technologies and applications:

- **Metal powder bed:** aerospace airframe, aerospace power systems and medical applications, with some defence applications.
- **Polymer powder bed:** medical (orthotics), consumer and creative industries, with some electronic packaging applications.
- **Multifunctional AM:** based largely on jetting techniques.
- **Metal powder feed:** aerospace airframe, aerospace power systems and power generation (repair) with some defence applications.
- **Binder jetting into ceramics:** some limited medical applications.
- **Metal filament (wire) feed:** aerospace airframe and aerospace power.
- **Photopolymer (resin) VAT systems:** creative industries, electronics and electronics packaging.
- **Hybrid processes:** these combine AM with other manufacturing approaches, such as machining, to harness the advantages of both processes.

Unlike other countries, detailed investigation of the UK AM research base suggests that there is a broad range of skills, and experiences spanning the entire AM supply chain, rather than a singular focus on one aspect [8]. More recent activity has included research into the effect of AM on business models and there is a new EPSRC network that will investigate the link between business models and AM.

The UK AM research funding to date has been evenly distributed across the AM supply chain, with activities being undertaken in the fields of:

- **Process innovation:** the development of new technology platforms.
- **Process development:** advancing the use of existing commercial platforms.
- **Enabling technologies:** the development of materials, software & energy sources.
- **Process validation:** relating to the commercial acceptance of existing platforms.
- **Product validation:** relating to the validation of discrete products made using AM technologies for specific applications [8].

However, even though there is a sound research base, it should be noted that the UK AM research community is highly fragmented with formal linkage and networks resulting mainly from finite length funded projects. This ad-hoc arrangement results in the risk of the possible breakup of a leading global research community once these projects are completed [8].

In summary, the UK holds leading positions in AM research. The UK also has experience and capacity to both develop new AM processes and apply existing processes, but the time-to-market for such processes is considerable.

Paul Howells - R&D Packaging Vice President, Unilever Limited

“3D Printing offers a competitive edge in the marketplace as it offers the potential for faster, higher performance and cheaper materials for packaging components.”

6 UK Research for Industry

The AM Specialist Interest Group [8] reports a firm grounding in the UK for AM research within the UK since 2007. This research and development knowledge has led the UK to be one of the world leaders in such activity for AM. An analysis conducted of UK industrial and public sector partners involved in projects funded through the Innovate UK, EPSRC and European Framework Programmes 6/7 streams for 2012 is shown in Figure 3. It is evident that the UK has seen considerable investment in AM initiatives across a very diverse range of industrial sectors [14].

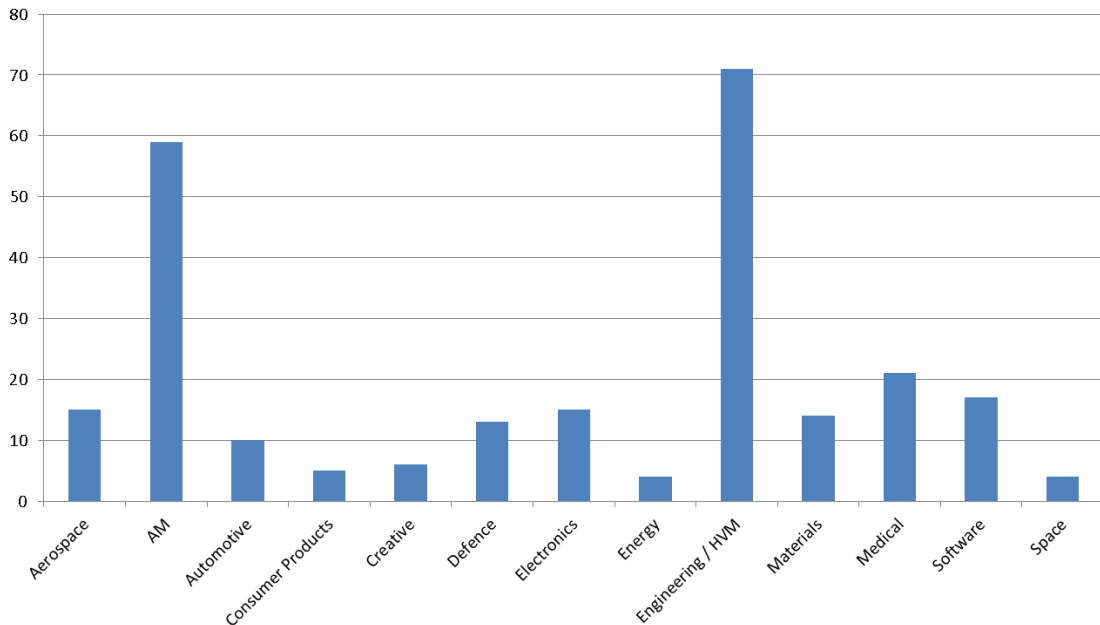


Figure 3: Number of UK entities involved in AM research projects by sector [14].

Although the UK is clearly engaged in research and development of AM technologies, it is evident that there are specific areas of strength and weakness in the value chain.

The UK is the leading European country in terms of engagement in EC FP7 AM research activity, with EC project participation and leadership exceeding all other countries, including Germany. The UK leads 45% of the current 20 FP7 projects with work packages focused on AM. Moreover, UK-based organisations constitute the largest proportion of participants of any eligible state with 23% of the 240 participants [8]. The UK does have some clear routes for exploitation, because of its strong position in EC and UK AM development programmes, which, by their nature, include process development, demonstrator creation and exploitation activities.

However, the dominance of other countries, such as the USA and Germany, in existing AM technology is a challenge for the UK. Investment in AM machinery development must address market need for production capable processes as well as provide technological leadership. There are significant opportunities for the UK in software development, material supply and the production of ancillary equipment. The development of additional capabilities such as Non-Destructive Testing (NDT) and Metrology should be a component of any UK AM development. However, it is important to recognise that the greatest potential for the UK economy lies in the exploitation of AM technologies by the high value manufacturing sector including Aerospace, Healthcare and high end Automotive. These sectors have been identified as key investment areas for growth in the UK, which compliments the position regarding AM. These areas require higher levels of continuous innovation because of strong global competition, where AM is likely to play a significant future role [8].

7 Challenges for Industrial Exploitation

For AM to be industrially exploited to its potential, a number of key areas need to be addressed. These range from technical issues to supply chain weaknesses. To build upon the strong UK position, such factors need to be incorporated into any National Strategy, bearing in mind the UK position in each area.

Listed below are a number of areas that need to be considered, particularly when managing risk associated with adopting AM technologies [8, 15, 16]. Due to the highly complex nature of the industrial exploitation landscape, this is not an all-inclusive list and challenges can vary in importance, and are dependent on application and industrial sector.

- Ignorance of the realistic benefits of AM - Industry is generally unaware of the potential advantages of AM and how it relates to their business.
- AM is a global industry, so there is a need to determine where to focus for maximum value for the UK.
- Strengthening the links between Research (TRL1-3), Innovation (TRL4-6) and Commercial exploitation (TRL7-9). Although the catapults play an important role it is important that funding organisations (Research Councils, Innovate UK and financial institutions) have a joined up approach.
- AM is fast moving, so the natural distillation process is too slow. There is insufficient learning/knowledge transfer.
- The level of investment both in infrastructure and skills is significant and will take time to realise. Early adopters need to have a nurturing environment to succeed and gain competitive advantage.
- Impact of standards and regulation – AM is a new area and there is no real structure in place.
- Productivity needs to be improved, including all aspects of the supply/process chain.
- Software issues need to be considered in terms of standards, skills required, digital rights managements, and exploiting what will be 'beyond .stl'.
- Many technical issues still remain in many AM processes including size of parts, powder recycling, in-process monitoring and control, stability, materials availability etc.
- Materials property data is lacking to enable the adoption of AM in component design.
- Quality control needs to be a large component of adoption, e.g. powder handling and management.
- Significant risks remain in adopting a business model using AM, the more disruptive applications need better risk mitigation strategies. There is an absence of knowledge/data on the full AM process chain requirements/capabilities and economics.
- Supply chain capacity is poor in most areas or relies on the efforts of a small amount of companies. For example, materials supply, equipment, post processing and validation.
- Education and availability of skilled people is poor.
- There is a need for de-skilling AM from 'post-doc level to technician'. Current AM application requires too high a level of operator education and training.
- AM presents new challenges around data security and these need to be understood and approaches developed.

- There is a need to identify and secure key Intellectual Property for the future generation of production AM machines and applied processes for the UK.
- There are open issues around liability ownership regarding industrial machines.

The challenges presented here are largely appreciated by industry. An instance of this has been stated by **Michael Straughan - Member of the Board for Manufacturing at Bentley Motors Ltd:**

“The current processing speeds of the machines and costs of the bespoke material feed stocks used are the major inhibitor to our long term targets, as it will be necessary to come to parity on the complete life cycle costing before full scale implementation in our business model are worthwhile”.

Another instance is where AM involving metal part production has been identified as an opportunity for industrial growth in the UK. Figure 4 pulls together many of the listed challenges for this area. However, due to the complex nature of the industry further development is needed to provide clarity how these challenges would be structured and subsequently addressed. A similar diagram could be produced for other processes that use polymers or ceramics.

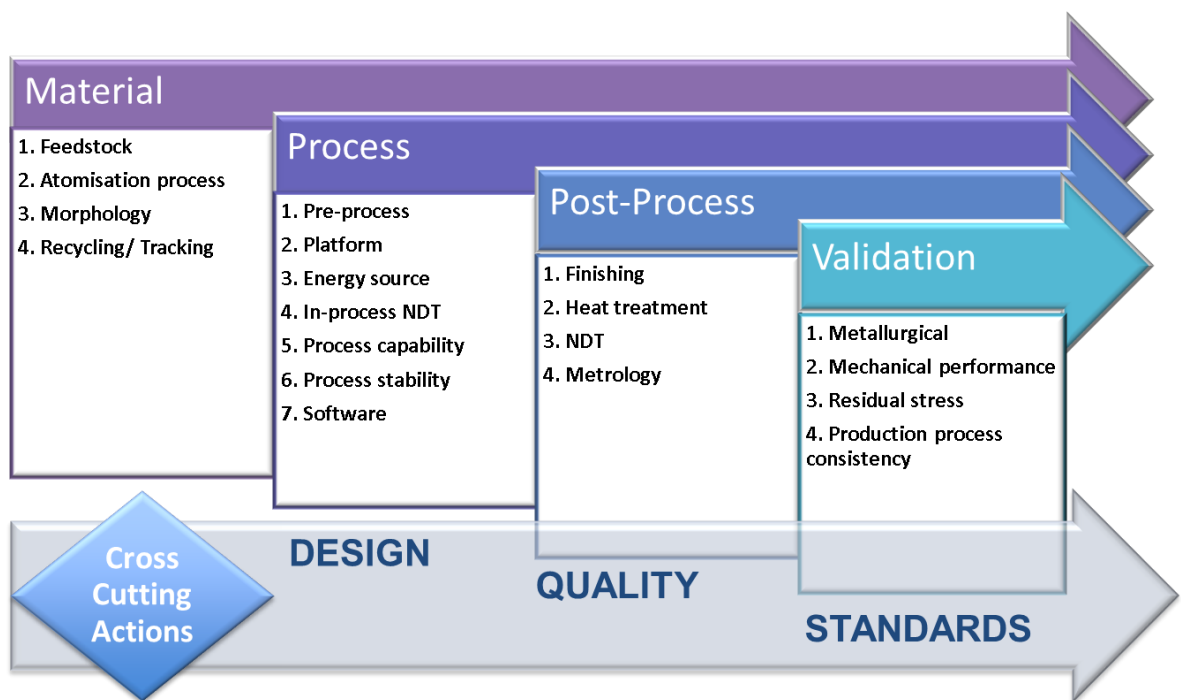


Figure 4 Schematic showing the challenges to metal AM across the process chain, (Courtesy TWI Ltd.).

8 Opportunities

Should the challenges to exploitation be removed, the global AM market is forecasted to be £67 billion by 2020. Many of the challenges identified present opportunity for the UK to gain a lead in the industrial application of AM. Industry consultation has indicated a prevailing view that the major opportunity is in the production of parts using AM. However, other areas such as equipment supply cannot be ignored.

AM will cause a paradigm shift in manufacturing, particularly in high value applications, where the UK must target if it is to compete effectively on the world stage. The growth in AM will mainly be application driven, and there is no reason to believe that the UK cannot benefit from this, given its strong knowledge intensive manufacturing base. Design of components, component systems and products will benefit greatly from the use of AM, and this needs to be at the core of any development activities involving AM. The opportunities, with a UK focus, can mostly be summarised as follows:

- **Process** - Bigger build platforms, new CAD systems, modelling and simulation for AM, surface finish improvements, speed/productivity. Although the UK has few platform providers, it does have considerable process knowledge in the use of AM machines, which is a competitive advantage. In recent years a number of the original 3D printing patents have expired which has opened up the market for the development of a new generation of production rather than prototyping machines.
- **Reliability** - The majority of AM systems have many issues with consistency of output. The UK process knowledge base can be also used in this area to develop more robust equipment that is more suitable for industry.
- **Materials** - The UK is well positioned to provide material property information, feedstock knowledge, Health Safety and Environment guidelines, recycling expertise particularly for polymers, cradle to cradle approaches, and work on the affordability of materials.
- **Standards** - Global standards are already advancing through the ASTM International Technical Committee F42 on Additive Manufacturing Technologies and The International Organization for Standardization (ISO) ISO/TC 261 Additive Manufacturing Technical Committee (where the UK has played a leading role), but there is an opportunity for BSI to build on their work to date to gain advantage in this area.
- **Data management** - This is mainly associated with quality monitoring along the process chain. In high value applications there is often a requirement to track from material to part and this requires more understanding in the field of AM. There are also issues in data capacity regarding file sizes, and software capability for CAD, and other areas.
- **Sustainability** - A greater depth of understanding is needed regarding the sustainability of AM as a manufacturing technique. The reduction of waste in AM, recyclability of AM polymers and metals.
- **Education and training** - This is a separate topic and is vital because it will be the next generation of engineers that will truly embrace the advantages of AM. AM is believed by many to be a useful tool in engaging children with STEM subjects. There is also considerable interest in the use of 3D printing within the home. There is the opportunity to harness this interest to the benefit of industry in general.
- **Funding business** - Provide a better environment for the funding of businesses through all phases of growth and sustainability where emerging technologies, such as AM, are being used as a differentiator.

- **Business models** - AM has the capability to change business models and open new markets. The business environment is dynamic and there is a need to understand what business models apply for AM and on what areas they are most dependent.

Also, bridging the so-called 'Valley of Death' in the TRL range 4-6 is a key element to exploitation and this represents opportunity, challenge and risk in the exploitation of AM. The Catapults have a role to play but also access for industry to invest in new technology is critical to complete the journey to commercial exploitation.

Global strategies have presented a digitally integrated vision of the manufacturing landscape. Approaches such as Industrie 4.0, include AM as a key enabler for such a vision to be realised because it offers the opportunity to create smarter supply chains and grow highly adaptive networks.

The opportunities for industry vary widely from sector to sector and hence are specific to each and even to each individual company. As to offer an insight into some of the specific perspectives of industry regarding AM opportunities, some key industrial statements are presented:

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

“Additive Manufacturing is seen as a key disruptive technology with applications across the land, sea and air sectors of BAE Systems. Advantages of this maturing technology will support the ongoing challenges of improved time to market and affordability by the introduction of novel solutions and optimisation of new products, supported by the reduction in both non-recurring activities and overall life cycle costs”.

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

“Additive manufacturing offers many potential benefits to pharmaceutical manufacturing and is an important area of investment for GSK. Rapid prototyping is one exciting application of additive manufacturing and is a tool our scientists and engineers can use to quickly develop optimal designs, allowing for rapid iterative testing and improvements of our models and devices. For devices, once the design is complete, the use of AM scales directly to manufacturing, representing a step change in transition from development to commercialisation by simplifying scale up and reducing the costs and complexities associated with tooling changes and part inventory that often require significant resources and time commitment”.

Michael Straughan - Member of the Board, Manufacturing Bentley Motors Limited

“In order to operate our high value manufacturing business more effectively we would like to reduce our dependency on as many tooling loops as possible whilst being flexible to offer more frequent product changes and reduced component complexity through part integration. The lack of tooling, the active ability to change components directly from design CAD files and the ability to process multiple materials at the same time with additive manufacture are matching our business needs. Hence, we can envisage greater integration of the technology throughout our design and development process such that it supports our targets of improved product quality.”

9 Conclusions and Recommendation

From the evidence presented in this document the following conclusions have been drawn:

- Additive Manufacturing is a key enabler in high value manufacturing. The design aspects in particular will produce a paradigm shift in the way components are designed, developed, and manufactured.
- The worldwide AM market forecast is £67 billion by 2020, if the technological and commercial barriers are overcome. These include sectors such as Aerospace, Medical devices, Automotive, and Consumer Products [1,2].
- The AM market in the UK has the potential to reach £5.7 billion and sustain 63,000 jobs by 2020. AM technologies will also underpin the High Value Manufacturing Sector which is currently worth £151 billion, and sustaining 1.6 million jobs [1,2].
- The UK is amongst the global leaders in knowledge generation and successful application of AM. However, there are deficiencies in the supply chain for manufacturing using AM. AM enables digital, on demand and localised manufacturing.
- The UK is currently well placed to take advantage of AM, however, national strategies around the world will raise the base level of competition, and give those nations a significant advantage as they co-ordinate and focus their respective capabilities and marketing efforts.
- Industry leaders and initiatives, such as the Foresight Report, are recommending the urgent development of a UK National Strategy on AM [5].
- Government involvement is needed to address market failures, and coordinate a fragmented AM community to develop approaches, particularly top-down, to address challenges to exploitation.
- Particular focus should be made on the intermediary Technology Readiness Levels, to ensure transition from laboratory to production.

Current AM market failings cover: technology awareness, skills, education, machine and materials supply, support to businesses in adopting AM, access to finance and clustering. It can be concluded that the only robust and sustainable approach to address these market failures and ensure maximum economic benefit from this new technology is to develop a Government supported UK Strategy for rapid, high value industrialisation of AM.

It is therefore recommended that Government engages with the already ongoing effort by Industry and Research to develop a UK National Strategy in AM. This will involve allocation of resources and direct involvement. The strategy development process will provide recommendations for investment. It is therefore, requested that Government seriously consider these recommendations.

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