HIGH VALUE MANUFACTURING LANDSCAPE 2016

INTERIM REPORT

IfM Education and Consultancy Services

UNIVERSITY OF CAMBRIDGE

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FOREWORD

The UK is a major competitor in the global manufacturing economy. Manufacturing which generates the highest value - High Value Manufacturing (HVM) – generates significant growth and economic benefits for the UK. The HVM sectors identified in this study add in the region of £275bn of Gross Added Value to the national economy per annum. HVM is achieved through the application of leading edge technical knowledge and expertise to the creation of products, production processes and associated services. This study reviews the global manufacturing landscape for the next 15-20 years in which UK companies will participate.

Specifically, this report updates 'A landscape for the future of high value manufacturing in the UK' developed jointly with The University of Cambridge Institute for Manufacturing and published by the Technology Strategy Board (now Innovate UK) in 2012 and draws upon a wide consultation with industry, academia and institutions. It identifies competencies that will allow companies to increase productivity and flexibility. By mastering a competency a manufacturer will be able to innovate across a number of product or process sectors. The report provides a landscape against which industry and government can make decisions which will create long-term value within the UK economy.

Whilst this study has not overturned any of the findings in the 2011/12 study, the following observations are new:

- **Digitalisation across the supply chain, smart and reconfigurable manufacture, automation, product and electronics integration** and **exploitation of new materials** will be widespread
- **National infrastructure investments** in rail, energy, and building and construction will offer significant opportunities for UK manufacturing
- The **aerospace, automotive and defence** sectors will strengthen their supply base as well as investing in product and process innovation that may have spill-over benefits to other sectors
- The **life sciences** sector, in particular those involved in the **bio economy, healthcare and food**, will increase their manufacturing capability.

There is an opportunity for national infrastructure projects to drive innovation in manufacturing, presenting an opportunity for government to maximise value for money. The report reviews and updates the trends and drivers for manufacturing and has established a newly defined set of industry challenges and revised its set of 'manufacturing competency themes'. Within the themes, the competencies have a much tighter general definition than the 'national competencies' described in the 2011/12 study. They offer cross-sector applicability, support the high level industry challenges and provide a framework to align the manufacturing research carried out in academia and the HVM Catapult.

Whilst industry is leading and undertaking investment, as developed in the sector strategies, institutional enablers have been reviewed and updated. Commentaries are made for these findings comparing with those of the 2011/12 HVM landscape study.

'Innovate UK continues to develop the manufacturing and materials strategy and has commissioned this work, a refresh of the work undertaken in 2011 and published in 2012, to identify new themes and changed priorities as one of a number of inputs to that strategy. The original report provided an excellent basis for strategy development and this update, which takes account of the many developments particularly as regards the development of industry-led, sector-based strategies, has identified a number of important themes, either new or significantly increased in importance and focus and as such builds in a very helpful manner on the valuable insights IfM have generated.'

Zoe Webster: *Head of High Value Manufacturing, Innovate UK*

'The HVM Catapult has been recognised as providing significant support to innovation in UK Manufacturing, as demonstrated by the national and industrial investment attracted to support its work. This report will help to develop the priorities for the Catapult and it reflects many of the themes on which industry is increasingly focused. It is a valuable input to the continuing work to develop a national strategy for High Value Manufacturing.'

Dick Elsy: *CEO HVM Catapult*

'We are in the middle of a global shift in the use of digitally-enabled technology and connectivity across the manufacturing value chain which has the potential to transform conventional production processes and business models, enabling a new era of products and services for more demanding customers and consumers. These changes have the potential to open new markets, improve UK manufacturing productivity, increase jobs and improve manufacturing sustainability. This report outlines a number of very important challenges which the UK needs to exploit in order to be at the global forefront of this revolution.'

Claire Marett: *Head of Manufacturing, Department for Business, Energy and Industrial Strategy*

'Bioscience is at the heart of key UK industries and it plays a vital part in supporting economic growth and social well-being. This report reflects that importance and in particular highlights some of the significant ways in which the UK's bio-manufacturing capabilities for the production of chemicals, biopharmaceuticals, food and fuels through industrial biotechnology can be advanced. Industrial biotechnology is predicted to have significant growth and impact over the next decade and is an important component of the UK bio economy.'

Alex Amey: *Associate Head of Business Interaction, Biotechnology and Biological Sciences Research Council*

'National defence and security science and technology priorities increasingly reflect the importance of collaboration across industrial sectors to harness leading edge capability. Moreover, embedding an implicit dual-use perspective in national strategy will improve the affordability of accessing capability benefits for defence, whilst improving export opportunities. This report, together with other related studies by the IfM, identifies many themes in common across the civil manufacturing sectors which are directly relevant to defence and security and thereby, the work underlying the report, also makes a valuable contribution to our own S&T strategy development. Some examples include: modelling, simulation and design; the emergence and evolution of digital manufacturing; advances in the processing of new materials, such as light alloys, composites, ceramics and nanomaterials; as well as developments in more mature materials, like steels. The report also reveals and integrates challenges and needs presently viewed as more unique to defence and security, including affordable, enduring low-volume manufacturing.'

Professor Ian Youngs: *Dstl Fellow, Defence Science and Technology Laboratory*

'This report builds on the previous work conducted by IfM and Innovate UK together with the other agencies represented on the Steering Team in developing the Landscape for High Value Manufacturing. There has been an extensive consultation with industry and academia and examination both of UK strategies and foresight work as well as international competitors' approaches and priorities in the field of High Value Manufacturing. New areas of importance have been identified and this provides insight for the continued development of national priorities in the field.'

Professor Andy Neely: *Head of University of Cambridge Institute for Manufacturing*

'Manufacturing's contribution to the UK economy is supported by new developments emerging from the UK's research base. EPSRC aims to invest in manufacturing research that will help solve some of the most serious challenges facing the UK today and in the future. This report highlights a number of important themes that will help inform the future direction of manufacturing research within the UK.'

Katie Daniel: *Manufacturing the Future Lead, Engineering and Physical Sciences Research Council*

INTRODUCTION

This interim report explores the emerging landscape for UK High Value Manufacturing (HVM) and the challenges that this landscape presents and is published for consultation purposes. Feedback is welcomed by the end of October 2016: see contact details at the end of the document.

This work is a refresh of the 2011/12 landscape study and builds on the work performed at that time. The 2011/12 study created a sound set of common themes around which the Technology Strategy Board (TSB, now Innovate UK) was able to build its strategy, align with other bodies such as the Research Councils and support the establishment of the HVM Catapult.

Since the 2011/12 Landscape there have been many developments, some stemming from or linked to that document: growth of the HVM Catapult and establishment of new Catapults; creation of the Industrial Strategies and associated investments sponsored by the Department for Business, Innovation and Skills (BIS now Department for Business, Energy and Industrial Strategy) , for example in the Aerospace Technology Institute; targeted Collaborative R&D calls from Innovate UK in line with the Landscape Study; the Manufacturing Foresight report and a general increased awareness of the importance of innovation and manufacturing.

National priorities are now focused on driving prosperity and productivity growth, strengthening the growth of SMEs, ensuring that the UK strength in research is translated to economic benefit and identification and development of local excellence and clustering. In the context of this focus on innovation for UK value creation, the landscape highlights the themes commonly seen in published documentation and in the opinions gathered through the consultation as important for HVM in the UK in the period out to 2030. The output can be compared to current plans as part of the Innovate UK and HVM Catapult strategy-setting process.

This work has not set out to duplicate the earlier work, nor to review the significant innovation developments already in hand across the breadth of the manufacturing landscape, but rather has been designed to take account of the new insights and capabilities that have been developed and to focus more directly on the challenges facing manufacturing industries. The processes have combined review of published sector strategy documentation with a very broad workshop-based consultation with expert groups 'triangulated' by focused discussions with key industrialists.

This new piece of work, conducted from 2014 to 2015 has focused on identification of actionable opportunities for additional value capture by UK industry and specific objectives are as follows:

- To produce an updated initial set of manufacturing competency themes, on which to build further, which is agreed by stakeholders across industry, government and research, informing Innovate UK HVM strategy implementation
- To provide an indication of areas worth exploring further, and support planning across appropriate sectors and government, such as: Innovate UK/HVM Catapult/UK Research Councils/Department for Business, Energy and Industrial Strategy (BEIS), Ministry of Defence (MOD) and Defence Science and Technology Laboratory (Dstl), integrating with the high level priorities of the HVM Catapult operational strategy.

The interim outputs from two other IfM studies concerning trends in international manufacturing research and the results of a survey of UK international research collaborations have been included as a cross check.

Suggestions are made for input the Innovate UK HVM strategy and work continues with the Research Councils and HVM Catapult to identify specific technologies emerging from the research pipeline and aligned to the principal manufacturing competency themes.

GOVERNANCE

The study was overseen by a Steering Team which comprised the following representatives. Note (*) asterisk indicates incumbent changed during the period of the study:

- Zoe Webster and David Wright, Head of High Value Manufacturing, Innovate UK* (Chair)
- Dick Elsy, CEO, High Value Manufacturing Catapult
- Clare Marett, Head of Manufacturing and Chris Carr, Deputy Director of Manufacturing, Services & Electronics, BEIS*
- Mark Claydon-Smith and Richard Bailey, Manufacturing The Future Lead, Engineering and Physical Sciences Research Council (EPSRC)*
- Alex Amey, Associate Head of Business Interaction, Biotechnology and Biological Sciences Research Council (BBSRC)
- Professor Andy Neely and Professor Sir Mike Gregory CBE Head, Institute for Manufacturing*
- Nick Rousseau, Head of International Innovation Strategy, BEIS

Other Steering Committee attendees included:

- Su Li, Associate Director, Business Engagement, BBSRC
- Keith Hodgkinson, Head of Innovation Policy, BEIS
- Prof Ian Youngs, Dstl Fellow

The Steering Committee was supported by a working team from the HVM Catapult and the University of Cambridge Institute for Manufacturing:

- Andrew Gill, Principal Industrial Fellow, IfM Education and Consultancy Services
- Paul John, Business Director, High Value Manufacturing Catapult

An academic advisory group from the University of Cambridge Institute of Manufacturing comprised:

- Dr Eoin O'Sullivan, Director, Centre for Science, Technology & Innovation Policy
- Dr Jagjit Singh Srai, Head, Centre for International Manufacturing
- Dr Robert Phaal, Principal Research Associate, Centre for Technology Management

TRENDS AND DRIVERS

The table below shows how HVM trends and drivers have developed since the 2011/12 study. Persistent trends and drivers are shown in black type. Red denotes new and amended data derived from the sector landscapes developed through desk research and workshop input. All trends and drivers identified in the 2011 study remain relevant, with sustainability drivers perhaps being somewhat subsumed within others concerning competitiveness, efficiency, and access to scarce materials.

Category	Description of HVM trends/drivers, with changes since 2011/12 study shown in red
Social	Ageing UK workforce, skill shortages (and into 2015+) with low mobility, with unclear impact from potential limitations on immigration
	Affluence increasing the pace of change
	Growing, ageing population increases demand, waste and imposes challenges for health, social care and food and priority of 'social responsibility'
	Culture and perceptions of manufacturing remain an issue for recruitment and skills supply
Technical	Shortening product lifecycles, increased variability and performance requirements, with increasing complexity of associated 'systems of systems' interactions
	Increasing prevalence of autonomous systems interacting with data to interact with physical and virtual life
Economic	Evolving global supply chains: economic power and opportunity continue moving east and beyond, but increasing transport costs encourage repatriation/reshoring
	Declining UK-based supply chain and increasing threats to SME from combination of skills and finance shortage, together with global OEM procurement policies
	Accessing credit and funding (including venture capital) and political impact on policy timeframes
	Producing in UK incurs high cost of factors of production
Environment	Increasing cost and scarcity driving importance of security of supply, use of fewer materials, including water, and less energy including water for all outputs as well as more reliance on renewable resources and increased asset 'life extension'
Political	Influencing and adapting to evolving government policy, tax and regulations to maximise competitiveness (including those related to emissions and sustainability)
	Supporting R&D and innovation remains a government priority, despite change of government
	New government's particular focus on productivity, strengthening of the supply chain, particularly the SME base, pulling innovation through from research to industry and export growth
Legal/ regulation	Impact of H&S regulations on new manufacturing technologies, (e.g. additive manufacturing, powder, etc.)
Market	Emerging new industries and methods and materials (e.g. photonics, renewable energy, non-metallics, additive layer manufacturing) with strategic opportunities for global leadership by UK businesses, particularly in multi-disciplinary areas
	Rising 'digital economy' and analytics and impact on 'traditional' products, processes and services design and manufacturing supply chain as well as creation of 'new' previously unseen market demands
International	Growth of foreign ownership of manufacturing capability, linked to inward investment
	Broadening innovation with 'ecosystems' through the global supply chain
	Significant UK and international investment in infrastructure may offset current limitations as well as offering manufacturing opportunities
	Ever-growing international competition, both for cost and quality of manufactured products, driving increased productivity

INTERNATIONAL RESEARCH THEMES REVIEW

IfM and IfM ECS have developed an overview of the emerging findings from this and two other projects[1] concerning the generation of value through international manufacturing research collaborations. The other projects are:

- *International manufacturing research priorities*: highlighting the research priorities of different countries (and how they undertake the prioritisation)
- *International manufacturing research collaborations survey*: identifying the structure and nature of recent or existing research collaborations, the contributions of various collaborators by country, their barriers to exploitation, and the barriers and enablers to their operation and meeting their objectives.

Although there is significant consensus around a number of key manufacturing research domain priorities between different countries, there is also significant variation in emphasis, investment levels and specificity, often reflecting perceived national research or industrial strengths. Key themes include:

- **The digitalisation of manufacturing:** ICT-enabled manufacturing technologies and systems. Particular effort is being put into 'cyber physical systems' (embedded software and sensors, and advanced measurement and control systems) and applications of the 'internet of things' to manufacturing, whereby 'intelligent' systems can be coordinated via the internet throughout entire value chains, allowing rapid development of new products, more efficient logistics, and more customised products and services.
- **Manufacturing and advanced materials:** The scale-up, integration and deployment of advanced materials are critical manufacturing research domains in all countries. This includes research into simulation technologies and expertise to enhance predictive (multi-scale) modelling.
- **Advanced manufacturing enabling key emerging technologies:** such as the translation of emerging technologies into high-value products and novel effective production technologies, in particular: advanced functional materials (as discussed briefly above), as well as novel biotechnology domains (e.g. synthetic biology and regenerative medicine), photonics, and nano electronics.
- **Manufacturing 'infrastructural' technologies:** such as advanced metrology, real-time monitoring technologies, characterisation, analysis and testing technologies, shared databases, modelling and simulation tools. There appears to be increased funding of test beds, pilot lines and related facilities.
- **Customer-focused manufacturing:** Increasing attention to more 'customer-focused' research endeavours, including tools for personalised and innovative product design, upstream design management, and on-demand manufacturing of customised products, product-service systems, etc.

1 *International manufacturing research priorities*, E. O'Sullivan and *International manufacturing research collaborations survey,* C. Featherston and T. Ulrichson, IfM Centre for Science, Technology and Innovation Policy, July 2015.

HVM CHALLENGES

The HVM landscape has been developed in a uniform manner across multiple HVM sectors and consists of the following elements as shown in the table below:

HVM Landscape Structure
Trends and drivers: key features and trends of the global and national environment, policy, strategy and market/customer needs which present particular competitiveness challenges, threats and opportunities for HVM.
Business capability: the ability of companies to respond to market/customer needs, competitiveness challenges and capture value. In particular, the ability to deliver products/services with certain competitive qualities/characteristics/functionalities, through the application of manufacturing and other competencies with the assets required to exploit it.
Manufacturing competency: a tool, technique or know-how (whether technical or operational) which may not be immediately visible to the user, but which – when combined with other competencies and resources – enables (one or more) capability/ies. These include: 1 Product technology competencies (i.e. related to the technologies delivering core application technology functionalities) 2 Materials competencies 3 Production technology competencies 4 Management/operational/supply chain competencies 5 Enabling technology competencies (e.g. measuring, characterising, testing technologies; advanced materials design/development competencies; ICT, modelling/simulation) 6 System engineering/integration competencies.
Support activities and infrastructure (including for skills and R&D) that enable businesses to respond to the changing global trends and drivers in a way that captures value for the UK in the future through the application of industrial capability (highlighting roles and priorities of appropriate institutional actor(s)).

Innovation has an impact across the HVM landscape and is driven by business capabilities and manufacturing competencies in concert. For example, the ability to manufacture a meta-material with novel properties (a manufacturing competency) could lead to improved product performance or the development of new products as long as the business is able to integrate the material into a production line (another manufacturing competency) and take the products to existing or new markets (a business capability).

Potential HVM challenges have been identified. An 'HVM challenge' has been defined as a significant *opportunity or threat* to UK industries' and firms' ability to create value in the global market place in 2030, which requires all of the following:

- new/enhanced *business capabilities* (to meet the above opportunities/threats)
- new/enhanced *manufacturing competencies* (to create the capabilities)
- new/enhanced action(s) by one or more *institutional actor(s)* to deliver on UK value potential

HVM challenges were identified and examined in a series of workshops and desk work using the following three steps:

Step one: the landscape detail was completed by desk research through extensive review of available sector strategy documentation.

Step two: a 'long list' of sector challenges was extracted from the landscape in workshops with industry, HVM Catapult and Research Councils and 'triangulated' with literature and further industrial consultation meetings.

Step three: key sector challenges selected in the workshops were reviewed by IfM to identify main challenge themes and compared to a review of international priorities in the field.

Sectors considered included:

1. End-use sectors such as: food, pharma/biopharma, agritech and agriscience, medtech, defence and security, aerospace, space, automotive, rail, marine, energy, nuclear, oil and gas and built environment
2. Cross-cutting sectors such as: chemicals, biotechnology, textiles, electronics and ICT and materials.

Cross-sector themes were also considered such as: robotics and automation, flexible manufacturing and design.

Examples of the challenges identified are summarised below:

1. Pervasive challenges, which will have an impact across the whole manufacturing economy, particularly as regards the digitalisation of the manufacturing supply chain, smart and reconfigurable manufacture, automation, product/electronics integration and exploitation of new materials, for example:
    - **Exploitation of ICT in increased flexibility of product manufacturing** for product customisation, new product introduction and end-of-life management
    - **Smart reconfigurable factories**, driven by simulation and modelling, for example, in aerospace/defence/automotive to cost-effectively manufacture complex and difficult high value products and components
    - Exploiting the various routes to **3D manufacture of printed electronics** to integrate functionality into a new breed of smart devices
    - Building new cross-discipline collaborations in **robotics and automation** to increase UK investment in fully automated and robot-assisted manufacture
    - Multifunctional and super-performing **textiles** with functionality through physical properties and built-in sensing and intelligence, to create high added value and offset downward pressures on the traditional sector
    - Improving the acceptance of and UK innovation in **smart and wearable devices**, including through enhanced validation and regulation in, for example, diagnosis and treatment in healthcare
    - **New materials design, qualification and integration**, connecting the innovation chain from lab to market to capture value for the UK from new materials development.

2. Challenges associated with national infrastructure investment priorities in areas such as rail, energy and building and construction, for example:

    - New **rail**ways including HS2, lightweight mobility, infrastructure and network optimisation to minimise environmental impact
    - New **energy storage** devices for power grid smoothing as demands for security and sustainability of supply increases
    - 'Active **buildings**' with energy capture, storage and control, to improve environmental efficiency
    - Strengthen the UK value capture in **small and medium nuclear reactor** design and build.

3. Challenges identified in sectors such as aerospace, automotive and defence, particularly around strengthening the supply chain, as well as new product and process innovation that may have potential for spin-out benefits in other sectors, for example:

    - Building new models of innovation across the supply/value chain in **aerospace** and **defence** (including SMEs), sharing innovation responsibility across tiers to increase the speed of introduction and uptake
    - Integrating design for manufacturing and new manufacturing processes across the **automotive** supply chain, strengthening the potential for value capture by UK manufacturers
    - Advanced, fuel-efficient **automotive** vehicle power units, exploiting new materials and coatings and smart technology to respond to emission reduction and efficiency demands
    - Unmanned **automotive** vehicles building in sensing, autonomy data analysis and modelling to reduce congestion and emissions.

4. Sector-specific challenges, particularly as regards the bioeconomy[2], healthcare and food, reflecting continued and/or growing importance of manufacturing in those sectors within the wider economy:

    - New, sustainable **food** manufacturing processes, reducing energy and water usage mitigating increasingly volatile resources in the low carbon economy
    - Intensified manufacturing, digital design and sustainable analysis of new and existing **pharmaceuticals and biopharmaceuticals:** pulling new products through development into UK rather than overseas manufacture
    - Point-of-care production, delivering tailored **pharmaceuticals and biopharmaceuticals** to individual patients supporting of cost-effective care, given pressures on ageing population, primary care and rising energy and transport costs.

A full set of the challenges identified and their sources is available online at: www.ifm.eng.cam.ac.uk/uploads/Resources/HVM_Report_Annex_3.pdf

2 The bio-economy is defined by the chairs of the UK's three bioscience leadership councils, comprising the Industrial Biotechnology Leadership Forum (IBLF), the Agri-technology Leadership Council (ATLC) and the Synthetic Biology Leadership Council (SBLC) as 'all economic activity derived from bio-based products and processes which contributes to sustainable and resource-efficient solutions to the challenges we face in food, chemicals, materials, energy production, health and environmental protection'. The definition used in challenge identification is new to the landscape and hence no direct comparison can be made to the outputs from the 2011/12 study, which used a different definition as a sub-set of trends and drivers.

MANUFACTURING COMPETENCIES

A new refined set of 'manufacturing competencies'[3] has been developed, which offer cross-sector applicability.

Manufacturing competencies identified to date in the study have been mapped across sectors to identify common themes and potential areas of cross-sector benefit from institutional investment. Examples of such potential cross-sector themes identified include:

- **Product technology:** electronics, photonics and power electronics; power generation technologies; sensor technologies; advanced and autonomous robotic technologies
- **Materials:** nanomaterials and nanotechnology; new composites; lightweight materials; biomaterials; other new materials and materials science
- **Management/operational supply chain:** supply chain and business model innovation
- **Enabling technology:** software development and management; (big) data management and analytics; Internet of things; autonomy; measurement, metrology, assurance and standards
- **Production technology:** additive manufacturing/3D printing; advanced assembly; tooling and fixtures; surface engineering (finishing and coating); remanufacturing; volume composite manufacture; biological and synthetic biology processing; process engineering, capability and efficiency development; control systems
- **System engineering and integration:** integrated design and manufacture; systems modelling and simulation; human machine interface.

Definitions of the full set of competency themes identified in this study can be found in the tables on the following pages. The sources include:

- The 2011/12 HVM landscape technologies and national competencies
- The 2013 Manufacturing Foresight report
- The 2013 'Factory of the future' report
- The HVM Catapult 'Technologies' list.

The themes span the above data, with the following exceptions from the original 2012 set of 'National Competencies', which are addressed rather through the challenges identified:

- Design and manufacture for sustainability and through life is a recurrent topic in a number of the challenges in, for example, food, automotive, active buildings, defence and aerospace
- 'Plug and play' manufacturing and flexible and adaptive manufacturing are addressed particularly in the exploitation of ICT to increase the flexibility of product manufacturing and smart and reconfigurable manufacturing
- Building new skills to support HVM is a very important enabling activity and is included in that section of the landscape.

3 Manufacturing competencies are defined as tools, techniques or know-how (whether technical or operational), which individually or in combination enable (one or more) business capabilities.

Product technology competency themes	
Plastic and silicon electronic technologies	Manufacturing, integrating and printing software and electronics, enabling products to be lower cost, lighter in weight, and providing more integrated functionality and lower energy consumption both in manufacture and use.
Electronics, photonics and power electronics	Highly reliable electronics with fast setup times with very complex builds and minimal tuning from initial production run; emission, transmission, modulation, signal processing, switching, and amplification with light; application of solid-state electronics to the control and conversion of electric power; wireless power transfer.
Sensor technologies	Sensing and connectivity; on-machine sensors; non-invasive sensing; efficient management of data from sensors for improved control, detection, predictive maintenance, etc.
Advanced and autonomous robotic technologies	Advanced systems to automate complex manufacturing processes such as assembly, logistics, materials processing and validation; nano-robotics; haptics.
Power generation technologies	New, high efficiency power generation technologies; regenerative power; power from previously wasted energy (scavenging); structural energy sources.
Energy storage technologies	Storing greater amounts of energy more efficiently and with minimal loss, with: intelligent charging; technological and infrastructural improvements to this end; structural batteries, fuel cells, ultra-capacitors and inductive charging.
Hydrogen fuel cells	New and more efficient H2-based fuel cells.
Fuels and lubricants	High performance fuels and lubricants (including the development of improved additives, and associated formulations).
Packaging	Packaging having active functions beyond the inert passive containment and protection of the product, and intelligent and smart packaging with the ability to sense or measure an attribute of the product, the inner atmosphere of the package, or the shipping environment.

Materials competency themes	
Nanomaterials and nanotechnology	Nanomaterials, nanocomposites and nano films; materials controlled at the nanometre level.
New composites	Design and rapid manufacture of new and existing high-quality composite products for improved functionality, light weight, low cost, high volume, thermal resistance, high strength and corrosion resistance.
Graphene	Exploration and exploitation of the many properties of graphene, including its strength, conductivity and suitability for biological applications.

Lightweight materials	Design and use of lightweight materials, especially for reduced cost, greater efficiency and achievement of weight targets.
New materials and materials science	Discovery and design of new materials, with an emphasis on solids. Exploiting the nature and history of new material processing to influences its structure, and thus the properties and performance, often not found in nature. For example in new metallic materials and metamaterials.
Biologically manufactured materials	Advanced design and manufacture of new biomaterials in food, energy, biopharmaceuticals, chemicals, and biotech, improving quality and yield, reducing waste and utilising synthetic biology processes and a wide variety of feedstocks.

Management/operational/supply chain competency themes	
Product and service integration	Integration of product and service approaches, including through-life capability development, improved monitoring, diagnostics and health management.
Supply chain and business model innovation	Improving information flow and forecasting, improved and new methods of supply and value chain co-ordination and business model optimisation.

Enabling technology competency themes	
Software development and management	New software to achieve or reduce the time to complete a manufacturing task, including testing, gauging, monitoring and analysis, supporting integration of software and electronics, augmented reality and human machine interface.
Big data management and analytics	Collection, storage, management and analysis of large amounts of data to create useful, useable information in support of manufacturing and supply chain management and improvement.
Autonomy	Automated systems with the cognitive ability to react to e.g. changes in consumer demand and product variability. Decision-making software; predictive control.
Internet of things	Networks of physical objects embedded with devices and connectivity, sensing, controlling and exchanging data remotely; the 'Ethernet of Everything', including the ability to add objects to this and derive benefits from its use.
Cloud computing	Exploiting ubiquitous network access to a shared pool of configurable computing resources, rather than local storage.
Mobile internet	Accessing internet resources from mobile devices.
Measurement, metrology, assurance and standards	Accurate, fast and efficient measurement and assurance, verification and validation; creation of new and associated standards.

Production technology competency themes	
Primary processes (casting, forging including alloying)	Advanced casting and forging techniques; including relevant near-net shape manufacturing; creation of high integrity components. New and exotic alloys to improve materials and component performance.
Joining	Advanced welding and joining techniques at both large and small scale, linked to understanding of materials process interactions; new bonding methods.
Laser processing	New and advanced laser cutting methods, laser drilling and laser welding technologies.
Other novel cutting, shaping and machining processes	Automatic deep-hole drilling; machining and characteristics mapping of large components.
Powder metallurgy	Materials or components made from metal powders, intricate features and good dimensional precision pieces with good finish, minimal waste and cost.
Additive manufacturing/3D printing	Deposition, sintering and extrusion to produce 3D objects from materials, resulting in minimal waste and cost.
Ultra-precision manufacturing	Creating new manufacturing processes and machines capable of producing emerging products of differing scale with nanometre accuracy.
Advanced assembly	Flexible, adaptive, rapid and high quality, low cost reconfigurable assembly.
Intelligent automation	Changing the way manufacturing machinery is designed, operated, supported, upgraded, re-used and retired.
Tooling and fixtures	Intelligent, reconfigurable tooling and tooling systems; low cost tooling.
Surface engineering (finishing and coating)	The development, application and validation of surface engineering treatments, exploiting materials performance and advanced designs.
Remanufacturing	Rebuilding and/or re-use of a product and/or associated materials; degradation study and associated mitigations.
Component manufacturing and processing using polymeric materials (plastics)	Novel manufacturing and processing of polymers for low-cost, high-volume applications.
Volume composite manufacture	Materials, layup, automation and curing developments to reduce the cost and cycle time and increase repeatability of composite manufacture.
Biological and synthetic biology processing (for Pharmaceutical and biopharmaceutical industries)	New and advanced industrial biology processing, including development tools and techniques, fill and finish, and specialist process analytical technologies for the pharma/biopharmaceutical sectors.
Biological and synthetic biology processing (for chemicals, materials and energy industries)	New and advanced biology processing, including development tools and techniques, fill and finish, and specialist process analytical technologies for the production of high value chemicals (incl. flavour & fragrances for food R&D bulk chemicals (including biofuels), natural products and novel materials.
Formulation	Innovation in food, nutraceutical and biopharmaceutical formulations; understanding stability predictions and links to packaging applications.
Process engineering, capability and efficiency development	Improvements to production processes, including: small-scale efficient manufacturing equipment; improved cleaning processes and materials; zero-waste manufacturing; novel sustainable catalysts (CHIRAL) for reaction steps; flexible and rapid manufacture for small batch complex therapies; small-scale processing; late customisation; scale up.

Post processing	Improving the post-processing techniques used in making consumer products, especially to reduce waste and pollutants.
Control systems	Development of process understanding and control mechanisms; in process monitoring; systems and process modelling; simulation and predictive tools for control.

Systems engineering/integration competency themes	
Integrated/hybrid technologies	Creating innovative products through the integration of new chemicals, materials, coatings and technologies, including biological and electrical.
Integrated design and manufacture	Through-process integration of design and manufacture to reduce waste, improve synergies, reduce the impact of obsolescence and allow structural design.
Systems modelling and simulation	Advanced analytical modelling and simulation to enable the prediction of system behaviours from a set of initial parameters and conditions.
Human machine interface	Optimising the interface between humans and machines, including design for intuitive use, augmented reality, immersive environments and smart robots.

ENABLERS

Industry is leading and undertaking investment, as developed in the sector strategies. Indeed, this investment is intrinsic in the definition of HVM challenge used in this study.

In support of this industrial investment, data gathered from the sector landscapes and published strategies, and drawn out during the consultations have been mapped onto the institutional enablers identified in the 2011/12 HVM landscape study, with changes highlighted in red in the following list. This sector-based approach has generated much new information, largely a reflection of new policy development since 2012:

Public policy and funding

- Maintaining the thrust and industrial ownership of established sector strategies and government environmental and energy policies
- Continued support for recently announced initiatives/new Catapult proposals, Aerospace Technology Institute, Advanced Propulsion Centre, Defence Solutions Centre, etc.
- Education and training policy to improve skills and increase the attractiveness of manufacturing as a career (sector-referenced specifically in e.g. agritech, textiles, chemicals, biotech, pharma, health, defence, automotive, nuclear, energy, built environment, digital and electronics, oil & gas, materials, flexible manufacturing and 'virtual engineering')
- Access to innovation support and associated investment, including SMEs, especially where focused on key manufacturing competencies
- Access to well-informed and targeted private finance
- Enhanced IP protection capabilities

Innovate UK, HVM Catapult (and other institutional structures such as Research Councils)

- 'Joining up' manufacturing strategy development and associated initiatives in a time of reduced government spending, thereby establishing a coherent set of priorities for HVM in the national context which supports industrial and public investment in key competencies and associated innovation realisation
- Enhanced access for SMEs to the innovation infrastructure and funding opportunities
- Maintaining current focus on competencies in novel manufacturing processes (including for new materials and materials processing, design and associated non-technical skills)
- Building national competency related to the digital economy sector and consider exploitation in the built environment and security sectors (subject to potential overlap with other bodies)
- Focusing on key process industry competencies and investigating how and whether they may be effectively translated to benefit the food, chemicals, biotech and pharmaceuticals sectors (including flexible scale-up capabilities)
- Enhanced structures and processes for technology, skills and knowledge exchange, standards development and other synergies within and between sectors and academia and industry, linked to knowledge of relevant funding opportunities and increased investment in scale up/new product introduction

Strategic and operational manufacturing management

- Optimisation of the UK manufacturing value chain to reflect the changing nature of manufacturing and so enable greater value to be generated by existing assets and increases the UK's share of the supply chain
- Enterprise resilience in highly dispersed value chains
- Business models for innovation risk sharing
- Development of tools and metrics for sustainable manufacturing

Strategic manufacturing and technology research collaborations

Collaborations are increasingly important as technologies become more complex and require expertise from a wide range of disciplines if they are to be successfully commercialised. The UK is not going to have all the answers but can seek to establish strategic international partnerships which benefit all parties. A survey and brief bibliometric exercise[4] suggests that key UK manufacturing collaborators are major industrialised countries. There are also opportunities to engage with emerging economies but these need to be approached carefully to ensure the outcomes are win-win both for the UK and partner countries.

This survey also identified that the capacity, capability and willingness of industry to absorb, adopt and deploy outputs from these collaborations are key barriers to exploitation.

4 *International manufacturing research collaborations survey*, C. Featherston and T. Ulrichson, IfM Centre for Science, Technology and Innovation Policy, July 2015.

EXAMPLE APPLICATIONS OF THE TOOLS AND TECHNIQUES DEVELOPED IN THE LANDSCAPE REFRESH

The landscape refresh has applied workshop processes that enabled visual outputs to be developed which may help to prioritise challenges and manufacturing competencies for the implementation of Innovate UK strategy development.

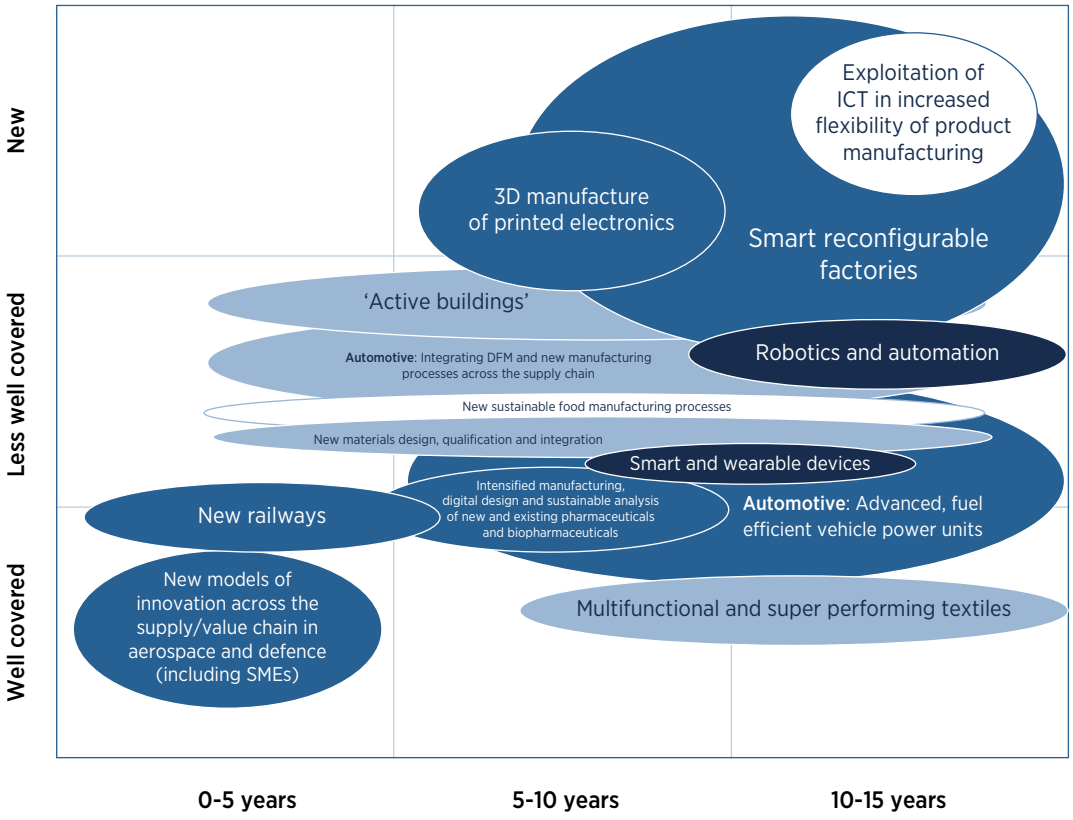
Two examples are shown here.

- Challenge portfolio mapping
- Manufacturing competency mapping

These examples need to be viewed with a caveat concerning sample size, as the results reflect the views of the relatively small numbers of – albeit knowledgeable – contributors in workshops. They are included to illustrate the potential benefits from the tools developed in manufacturing strategy development.

1. Challenge portfolio mapping

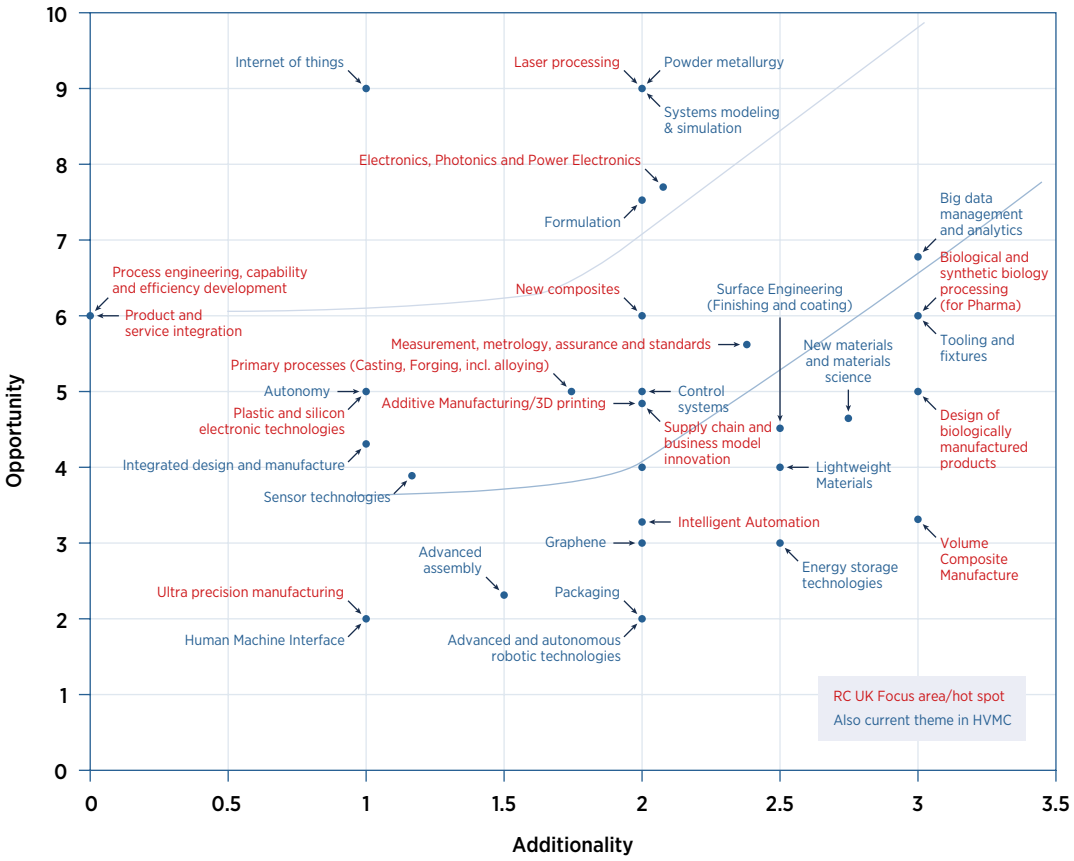
Delegates from industry, academia and government developed and assessed 'HVM challenges' in a series of workshops in 2015. An example of the output from these workshops is shown in the figure below.



Delegates were asked to indicate the timing when the challenge might have impact (horizontal axis) and the extent to which they felt the challenge was presently being addressed (vertical axis). They also indicated their confidence in predicting the challenge (darker blue implies greater confidence) and voted on the potential importance for value capture in the UK by 2030. These results are all captured in the figure.

2. Manufacturing competency mapping

This output remains 'work in progress'. Delegates from the EPSRC, BBSRC and Dstl were asked to map their current pipeline of research programmes onto the manufacturing competencies. Particular attention was paid to identifying both new technologies and new manufacturing processes which may require development effort in the next two to three years. These particular programmes were then assessed by representatives from the Knowledge Transfer Network (KTN) to assess opportunity for value capture in the UK and the level of government action ('additionality') which may be required to deliver that UK value by 2021.



Portfolio investment priorities may be indicated by those themes which lie above the superimposed solid line, with the higher dotted line indicating a possible cut off as available resource reduces. It should be noted that although these results are indicated as point positions, as with any research and development portfolio, there are potential ranges of outcome reflecting the inherent risks and uncertainties. It should also be noted that these results remain to be validated.

PRIORITIES FOR INPUT TO INNOVATE UK HVM STRATEGY DEVELOPMENT

Four general themes are suggested as input to the Innovate UK HVM strategy:

- Pervasive challenges, which will have impact across the whole manufacturing economy, particularly as regards the **digitalisation of the manufacturing supply chain, smart and reconfigurable manufacture, automation, product/electronics integration** and **exploitation of new materials**
- Challenges associated with **national infrastructure investment priorities** in areas such as rail, energy, and building and construction
- Challenges identified in sectors such as **aerospace, automotive and defence** particularly around **strengthening the supply base as well as new product and process innovation** that may have potential for spin out benefits in other sectors
- Sector-specific challenges, particularly as regards the **bio economy, healthcare and food**, reflecting growing importance of manufacturing in those sectors within the wider economy.

The joining up of manufacturing strategy development and innovation initiatives, for example with infrastructure investments, presents an opportunity to maximise value for money in a time of reduced government spending. It should be noted that since the consultations which contributed to the development of this report, Research UK has been formed, bringing together the separate research councils and Innovate UK, and Innovate UK High Value Manufacturing has been combined organisationally with Innovate UK materials to form Innovate UK Manufacturing and Materials.

Manufacturing competency themes are suggested as an important mechanism to support the alignment of national manufacturing innovation investment across agencies and with industry. They offer a common language and categorisation programme for review between Research UK and the HVM Catapult, as well as with other stakeholders such as MOD.

NEXT STEPS

Work continues with the Research Councils and HVM Catapult to identify specific technologies emerging from the research pipeline and aligned to the principal manufacturing competency themes. This work will help further inform the future Innovate UK High Value Manufacturing priorities.

This work also forms part of the input to the ongoing development of the HVM Catapult strategy and will help inform investment priorities for resource and capability development in the HVM Catapult.

Related work is under way on the development and implementation of national strategies for digital manufacturing, through-life engineering services and the machinery and components sector. These are all particularly important for small and medium enterprises in exploiting the national priorities around HVM.

Consultation

This is a consultation document. If you would like to provide input or feedback, please email Sarah Fell by 31 October 2016 at skbf2@cam.ac.uk

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