Government Office for Science

Foresight

International approaches to understanding the future of manufacturing

Future of Manufacturing Project: Evidence Paper 26

Foresight, Government Office for Science

International approaches to understanding the future of manufacturing

By

Dr. Eoin O'Sullivan & Nicola Mitchell

University of Cambridge

October 2013

This review has been commissioned as part of the UK Government's Foresight Future of Manufacturing Project. The views expressed do not represent policy of any government or organisation.

Contents

Acknowledgements

The authors of this report would like to acknowledge the help and support provided by:

- the Government Office of Science Foresight team, and in particular Paul McCaffrey, Mohammed Shabier and Emily Eakins;
- Carlos Lopez, Institute for Manufacturing, University of Cambridge;
- the Science & Innovation Network, and in particular Kinchit Bihani, Sam Leng, Seiko Oya, and the teams in Germany and China;
- Professor Sir Mike Gregory, Tomas Coates Ulrichsen and Antonio Andreoni (University of Cambridge);
- Professor Dr Engelbert Westkämper (Fraunhofer IFF), Dr Stephanie Shipp (Institute for Defense Analysis), and Richard Neal (Integrated Manufacturing Technology Initiative) for permission to use figures reproduced in this report;
- the Gatsby Charitable Foundation.

Executive summary

Manufacturing industries are going through a period of significant change and uncertainty, with opportunities and challenges to future manufacturing competitiveness driven by a range of factors including: the increasingly complex and globalised nature of industrial systems; the dramatic reduction in manufacturing timescales and acceleration of technological innovation; and the growing need for sustainable, resource-efficient production. This report reviews international analyses of the future of manufacturing carried out in important manufacturing economies. In particular, this review explores foresight-related studies of trends and drivers influencing the changing nature of manufacturing, manufacturing capabilities important for addressing future challenges and opportunities, and the implications for economic value creation and growth.

This report, commissioned as part of the UK Government's Foresight Project on 'The Future of Manufacturing', aims to highlight effective approaches to manufacturing foresight-related analyses carried out by international governments, industrial organizations and research communities in key economies. Although relatively few formal manufacturing foresight exercises have been carried out internationally in recent years, there have been a variety of forums, conferences and other initiatives addressing themes related to the future of manufacturing which are also considered in this review

The studies reviewed in this report have involved a variety of different stakeholders, methodologies and contexts. Consequently, care should be taken in comparing approaches or in identifying practices appropriate to the UK. Nevertheless, it is hoped that this review can support the work of the UK Manufacturing Foresight team and Lead Expert Group by identifying potentially useful manufacturing foresight practices, dimensions of analysis, and thematic focus areas; as well as providing insights into the priorities, policies and strategies of competitor economies. Key themes and observations from this review of international approaches to exploring the future of manufacturing are summarised below.

Key themes and observations

The systems-nature of manufacturing

A key feature of recent international analyses of the future of manufacturing is the emphasis on the *systems*-nature of manufacturing. The dynamics of competitive advantage between national manufacturing systems cannot be fully explained by examining individual production technologies and manufacturing-based sectors alone. Not only are many of the most important modern high tech products themselves systems, but their manufacture relies on a range of industries contributing and integrating components, application subsystems, production systems and service systems. Furthermore, modern manufacturing systems are constructed around supply chains which may interact in highly complex ways. Many policy-related recommendations point to the importance of government taking an 'ecosystem' view of manufacturing; also highlighting that many of the most important manufacturing-related challenges (e.g. industrial sustainability) require 'whole systems approaches'. Several studies highlight the blurring of traditional sector boundaries; and the complex interdependencies between manufacturing systems and national innovation systems.

Manufacturing system elements and configurations

With increasing attention being paid to the challenges facing different parts of 'manufacturing ecosystems', many manufacturing foresight-related exercises make particular efforts to distinguish between different categories of manufacturing system elements. For example, in some international studies particular care was taken to distinguish between:

- **Different types of manufacturing firms**, in particular factory equipment makers (capital goods) and factory users (consumer goods)
- **Different manufacturing 'enterprise functions'** (firm-level value chain stages): Innovation processes and product development; production techniques and machines; service and usage; as well as business models; logistics and planning; skills and workforce demographics.
- **Established and emerging sectors,** i.e. between those sectors with relatively established value chains, markets, supply chains, standards, product designs, etc and those sectors (often based on novel technologies) where there is significant uncertainty regarding how such features will evolve
- **Firms of different size and scope:** Small & medium-sized enterprises and major manufacturing firms (which have significant influence across value chains, global awareness and R&D insights)
- **Categories of manufacturing-related R&D:** Types of research activity with the potential to advance different manufacturing capabilities (unit process technologies, machine level technologies, manufacturing enterprise systems, etc)

These distinctions can have important consequences for manufacturing foresight exercises, for example in terms of identifying particular manufacturing stakeholders groups with important perspectives and insights.

Value creation and capture

A particular emphasis of international manufacturing policy discourse and foresight studies is on how manufacturing systems need to be configured to support economic value creation and capture. Many recent analyses have gone beyond identifying promising production technologies or exploring trends influencing the competitiveness of manufacturing firms, to investigate the issues associated with *national* economic value capture. Particular attention is given to anticipating the potential to retain and create jobs; and the potential to retain and attract investment. Some advanced economies are putting significant effort into understanding the challenges to capturing value from production within high wage countries.

Another theme receiving significant attention is the role of manufacturing in capturing value from novel science and technology emerging from the national research base; and the interdependence between production activities and technological innovation itself. There is growing awareness that a knowledge economy that loses interaction with its production base may lose the ability to innovate the next generation technologies and the potential to participate in important emerging industries of the future. A number of international foresight-related analyses – notably in Germany and Japan – have addressed the role of manufacturing for capturing socio-economic value, in particular the contribution of production (and emerging production technologies) to tackling a range of social 'grand challenges', such as healthcare, mobility, climate change and sustainability.

Future of manufacturing analyses: trends, capabilities & value

Despite variations in methodological approach and national context, the studies considered in this report typically explore some or all of the following:

- **Trends & Drivers** influencing the changing nature of manufacturing systems
- **Challenges** to the competitiveness of national manufacturing firms and manufacturing 'ecosystems' more generally (which arise as consequences of the trends and drivers)
- **Capabilities & Success Factors** associated with meeting challenges (and opportunities)
- **Value Creation:** What elements (and associated configurations) of modern manufacturing systems have the potential to capture significant value for the local economy and/or contribute to social value creation (including 'grand challenges')?

Some of the international approaches to analysing these themes (and associated categories of subtheme) have the potential to usefully inform the 'conceptual framework' being developed as part of the UK Manufacturing Foresight Project.

Manufacturing foresight tools, methodologies & practices

The international studies of the future of manufacturing reviewed in this report used a broad range of methodologies. The approaches used were mainly qualitative (e.g. surveys, expert panels, interviews) or semi-quantitative (e.g. Delphi, technology roadmapping). Many studies used a mix of methodologies, combining insights from key experts with broader engagement with manufacturing stakeholder communities, backed up by reviews of the existing evidence base.

The selection of methods adopted varies depending on a range of factors related to the foresight studies, e.g.: allocated time and resource; scale and scope (transnational, national, regional); the time horizon; etc. These factors, in turn, reflect the missions and perspectives of the study sponsors and the industrial structures and strengths of the economy. Despite these contextual factors, it is hoped that the range of methodological options illustrated in this report suggest approaches that may be worth considering by the Government Office for Science Manufacturing Foresight team. For example, one potentially noteworthy practice, observed in a number of countries, involved the foresight teams systematically engaging with established forums or conferences of different manufacturing stakeholder groups to gather more collective insights from those communities.

Variations in perspectives, context and scope

The studies reviewed in this report vary significantly in a number ways, with consequences for how their findings should be compared and interpreted. Key sources of variation include:

- **Definition:** studies define 'manufacturing' differently, with consequences for the scope of foresight enquiry. Some focused on future production technologies, while others addressed the entire industrial value chain; some studies restricted their analysis to 'traditional sectors' (e.g. steel, automotive, etc), while others addressed all product-based industries including emerging science and technology-based sectors

- **Stakeholders:** The ‘future of manufacturing’ studies explored in this report were led by and engaged a wide range of organizations, including: Trade ministries; research & education ministries; research councils; industrial development agencies; trade associations; think tanks; professional societies; national academies; etc
- **Time horizons:** Some studies considered shorter term trends and priorities, e.g. visions of manufacturing in 2020; others took much longer term perspectives, some exploring manufacturing systems as far away as 2050
- **Year of study:** The year the study was carried out may have consequences for particular emphases or conclusions, e.g.: exercises carried out before the global financial crisis have less emphasis on manufacturing employment; rapidly maturing emerging technologies receive greater attention in more recent studies; etc.

Given the significant variations in emphasis and purpose of those studies reviewed in this report, care should be taken when comparing international studies and interpreting their findings; and – in particular – when considering the adoption (or adaption) of particular approaches to a UK context.

Future of manufacturing analyses: priority actions

Two broad classes of recommendations were observed within the studies reviewed: (a) research & innovation investment priorities, (b) strategic policy-related priorities. Despite some variations between nations, there was significant consensus on number of high priority research domains, including:

- Sustainable manufacturing
- Production technologies and biomanufacturing
- Simulation & modelling
- Additive manufacturing
- Responsive production networks

Similarly, several policy-related themes were common to many international analyses:

- Public Private Partnerships (for addressing challenges to competitiveness)
- The manufacturing SMEs of the future
- The role of standards in support of manufacturing competitiveness
- Future challenges for regional manufacturing clusters
- The manufacturing workforce of the future

Although significantly influenced by national industrial and innovation system contexts, the priority actions identified by international manufacturing foresight exercises – and , in particular, the rationales for prioritising particular research and policy domains – offer useful insights into the key challenges perceived by competing economies, as well as suggesting potential themes worthy of particular study in a UK context.

1. Background and introduction

This review of international approaches to exploring the future of manufacturing was carried out to support the work of the UK Government Office for Science Manufacturing Foresight team and Lead Expert Group during the design phase of the '*Future of Manufacturing*' study. In this context, this review focused on identifying potentially useful manufacturing foresight themes, dimensions of analysis, and practices, as well as providing insights into the manufacturing priorities and policies of competitor economies. In particular, this report aims to highlight effective methods used in recent manufacturing foresight-related analyses carried out by international governments, industrial organizations and research communities in key manufacturing economies. This introductory section gives a brief overview of the contexts within which these foresight exercises were carried out, highlighting key themes within national policy debates, as well as differences between national manufacturing systems, and some variations in the perspectives and emphases of the stakeholders involved.

The primary source materials reviewed in this report are published manufacturing foresight-related studies (including manufacturing-related R&D prioritization exercises, etc) as well as reports of national workshops and symposia addressing themes related to the future of manufacturing. This study reviewed analyses from a range of important manufacturing economies, with particular attention paid to the United States, where there has been a lot of recent policy activity; and to Germany, where there is a long-standing tradition of systematic analysis of the future of production. This analysis is supplemented by reference to the academic literature and industry press articles which address issues related to the future of manufacturing.

It should be noted that the number of recent formal national manufacturing-related foresight exercises identified in this review is relatively small; and the majority of those studies are qualitative in nature (see Appendix 1 for details of a selection of the international foresight studies reviewed). Furthermore, these exercises have been carried out by a diverse set of organizations, each with their own perspectives, thematic areas of focus, methodologies and timeframes of interest. The relatively sparse and diverse nature of available foresight analyses makes it challenging to draw specific conclusions about their relative effectiveness, quality and findings. Nevertheless, it is hoped that this review of international approaches to understanding the future of manufacturing will support the work of the UK Government Office for Science Manufacturing Foresight team and Lead Expert Group by providing insights into the priorities of key manufacturing economies; illustrating a variety of foresight-related methodologies; and offering options for potential dimensions of analysis and foresight practices which may be usefully adapted or adopted in a UK context.

The studies explored in this review were, of course, carried out within their own particular national economic and industrial contexts; and against the backdrop of local policy debates related to the future of manufacturing. In this introductory chapter we give a brief overview of key themes emerging from these international policy debates, in particular highlighting influential articles which have been widely cited within local foresight studies. This chapter also contains a brief discussion of key sources of difference between the various manufacturing foresight studies, in particular highlighting variations in stakeholder perspective, thematic emphasis, time horizons considered, national industrial structures, etc. These contextual variations should be borne in mind when considering the potential of adopting or adapting particular manufacturing foresight approaches to a UK context.

This introductory section concludes with brief summaries of the remaining sections of this report.

1.1 The future of manufacturing: international policy discourse and debate

The manufacturing foresight exercises explored in this study were typically carried out against the backdrop of broader policy debates regarding the potential of manufacturing to rebalance national economies; the interdependence of manufacturing and innovation; and the challenges to capturing economic value from production-related activities. Within these national conversations, a number of forums, thought leaders and individual articles have been especially influential in shaping the discourse and debate. This section gives a brief overview of selected articles (and other commentary) that have been influential in highlighting key themes related to the future of manufacturing.

> *"Analysing and developing policies to support the future of manufacturing should focus on public-private innovation ecosystems to develop and deliver required manufacturing technologies and systems"*
>
> - Gregory Tassey, Chief Economist, National Institute for Standards & Technology

An important theme in many of the most influential recent articles is the emphasis on **the *systems*-nature of manufacturing**. Gregory Tassey's '*Rationales and mechanisms for revitalizing US manufacturing R&D strategies*' [Tassey, 2010][1] makes the case that the dynamics of comparative advantage between economies cannot be fully revealed by simply analysing individual technologies or particular industry sectors. Tassey points to the complex interactions and interdependencies between industries associated with the manufacture many high tech products. Not only are many of the most important modern high tech products themselves systems, but their manufacture relies on a range of industries contributing and integrating components, application subsystems, production systems, service systems, etc. Without economic frameworks and metrics that can account for the reality of these complex 'manufacturing ecosystems' [Van Opstal, 2010], it will not be possible to identify how economies can capture wealth from these dynamic interacting value chains, how to enhance national manufacturing competitiveness, or how to understand the impact of specific manufacturing-related policies.

> *"In the long term... an economy that lacks an infrastructure for advanced process engineering and manufacturing will lose its ability to innovate."*
>
> - Gary Pisano and Wily Shih, Harvard University

Another key policy theme of has been the interdependencies between manufacturing and technological innovation [Vest, 2009; NAE, 2012]. One of the most high profile articles addressing this issue is the 2009 Harvard Business Review paper by Gary Pisano and Wily Shih, '*Restoring American Competitiveness*' [Pisano, 2009], which warns that deterioration in a nation's manufacturing capabilities will inhibit its ability to innovate new generations of technology-based products. In particular, they argue that once production activities are off-shored, it may not be possible to retain critical process-

[1] Tassey's article appeared in the Journal of Technology Transfer, Volume 35, Number 3 (2010) – an issue that also contained six other articles in the form of responses to his '*Revitalizing US Manufacturing R&D*' paper from a variety of commentators on manufacturing and innovation policy. Tassey's article is cited in the Obama administration's '*National Strategic Plan for Advanced Manufacturing*' and associated recent policy documents.

engineering expertise and other know-how (which are sustained by regular interactions with manufacturing). Furthermore, without these capabilities, it becomes much harder for firms to carry out advanced R&D on next-generation process technologies, which in turn means they may lose the ability to develop such new processes, and ultimately the ability to develop innovative new products.

Suzanne Berger, co-chair of MIT's high profile Commission on 'Production in the Innovation Economy' argues that for many important emerging technology sectors it is becoming extremely hard to separate R&D, design and production [Berger, 2011], suggesting that countries which nurture strong linkages between technology research labs, design and manufacturing activities will derive greater economic benefit from their innovations. Of particular interest, in this context are the 'manufacturability' and scale-up challenges of emerging technologies [Dugan, 2010; Tassey, 2010; Berger, 2011]. Berger suggests that, for many important emerging technologies, a key source of the interdependence between manufacturing and innovation arises from 'challenges in scaling up activities from laboratories through start-ups into full production of new products and services'.

> *"...In today's emerging technology sectors, R&D, design, and production appear to be harder to separate..."*
>
> - Suzanne Berger, MIT

> *'Abandoning today's 'commodity' manufacturing can lock you out of tomorrow's emerging industry…'*
>
> - Andy Grove, former Intel CEO

In a highly cited BusinessWeek article 'How America can Create Jobs', former Intel CEO, Andy Grove, highlights the importance of 'the phase where companies scale up... work out design details, how to make things affordably, build factories, hire by the thousands' [Grove, 2010]. In particular, Grove argues that an emerging industry needs an effective ecosystem where 'technology know-how accumulates, experience builds on experience, and close relationships develop between supplier and customer'.

This emphasis on **economic value creation and capture** from production – identifying aspects of manufacturing which are sources of sustainable high value jobs and prosperity – is reflected in the manufacturing policy debates of many countries. In Germany, the National Academy of Science & Engineering convened leading experts to address challenges to future of German manufacturing competitiveness [Acatech, 2010], in particular exploring ways to capture added-value and employment in a high-wage economy. The work of Christian Brecher and colleagues at the Aachen Cluster of Excellence for 'Integrative Production Technologies for High Wage Countries' has highlighted the importance of exploring ways to achieve greater variability of products while at the same time being able to manufacture them at cost-levels close to that of mass production [Brecher, 2012; Klocke, 2009; Schuh, 2011]. In Japan, Professor Takahiro Fujimoto, highlights the importance of systems thinking and design [Fujimoto, 2007; Corwin, 2009; Fujimoto, 2011], suggesting that for Japan, there is significant comparative advantage to be gained from manufacturing products which require sophisticated levels of coordination in terms of production engineering, design and technology.

> *"In order to achieve a sustainable competitive advantage for production facilities in high-wage countries, one must find ways of increasing the variability and individuality of products while at the same time producing them at mass production prices."*
>
> - Fritz Klocke, Fraunhofer IPT

1.2 Variations in national context, industrial structures & stakeholders

The international analyses of the 'future of manufacturing' identified in the course of this review were all carried out within particular national contexts – i.e. within countries with different industrial structures and strengths, and innovation systems with different configurations, scale and levels of maturity. Furthermore, the different exercises were led by a diverse set of organizations, each with their own perspectives, thematic areas of focus, and timeframes of interest. Consequently, significant care should be taken when comparing these international studies, when interpreting their findings, and – in particular – when considering the adoption (or adaption) of particular approaches to a UK context. In this regard, important **sources of variation** within the different foresight exercises include:

- **Lead stakeholders:** International studies of the future of manufacturing were led or commissioned by a broad range of manufacturing stakeholders, including: Ministries of Trade & Industry; Ministries of Research & Education; national research foundations; industry development agencies; trade associations; think tanks; national academies; etc. The nature and objectives of the foresight studies are likely to be significantly influenced by the missions, perspectives and priorities of the organisations that commissioned the studies.

- **Definitions:** There are significant variations in the definitions of 'manufacturing' itself, and consequently for the scope of foresight enquiry. Some exercises are primarily focused on future production technologies while others address issues across the entire industrial value chain; some studies restrict their analysis to a narrow set of 'traditional sectors' (e.g. steel, automotive, etc), while others address all product-based industries. Issues related to the definition and scope of 'manufacturing' are discussed in more detail in Section 2.

- **Thematic focus & objectives:** Although all the studies explored in this report address the future of manufacturing, there are significant variations in emphasis and focus (largely reflecting the objectives of the organization leading the study, as discussed above). For example, some studies are primarily focused on identifying manufacturing-related research priorities, while others on identifying policy priorities related to skills and infrastructure. Particular policy-related thematic focus areas are discussed in more detail in Section 4.

- **Methodologies:** The international foresight studies reviewed in this report used a broad range of methodologies, which were mainly qualitative (e.g. surveys, expert panels, interviews, etc.) or semi-quantitative (e.g. Delphi, technology roadmapping, etc.). The different methodological approaches deployed by the studies explored in this review are discussed in more detail in Section 3.

- **Time horizons:** The studies reviewed in this report considered the 'future of manufacturing' over a range of different time horizons, some considering shorter term trends and priorities associated with a vision of manufacturing in 2020, while others took much longer term perspectives, some exploring what manufacturing systems might look like as far away as 2050. The choice of time horizon has significant consequences for methodologies selected and conclusions reached.

- **Year of study:** Although this review focused mainly on manufacturing foresight studies carried out in the last 5 years, the year the study was carried out may still have significant consequences in terms of particular emphasis or conclusions. For example, foresight exercises carried out before the start of the global financial crisis of 2007/2008 have less emphasis on manufacturing employment.

A selection of the **types of stakeholder initiatives, varieties of studies, and countries considered** in the course of this review are briefly outlined below. Particular attention was paid to the US, where there has been a lot of recent manufacturing-related policy activity; and to Germany, where there is a long-standing tradition of systematic analysis of the future of production, but the report also draws from selected studies carried out in a range of other economies with important competitive manufacturing strengths[2]. In addition to national studies, this review also looked at a small number of high profile analyses carried out by multinational organizations.

United States: The future of manufacturing has received significant attention by US policy makers and other stakeholders in recent years. At the end of 2009 the Obama administration issued a 'Framework for Revitalizing American Manufacturing' [EOP, 2009]. Following on from this there has been a range of studies, summits and policy initiatives, including the recent '*National Strategic Plan for Advanced Manufacturing*' [EOP, 2012]. US activities exploring the future of manufacturing have been carried out by a variety of stakeholders including:

- **The President's Council of Advisors on Science and Technology**, which published a substantial '*Report to the President on Ensuring American Leadership in Advanced Manufacturing' [PCAST, 2011]*
- **The National Institute for Standards & Technology,** hosted an interagency workshop exploring the 'technology needs for long-term US Manufacturing Competitiveness' [NIST, 2011]
- **The National Competitiveness Council,** which launched a 'US Manufacturing Competitiveness Initiative' [USMCI, 2012]
- **The National Academy of Engineering** which hosted symposia on, for example: '*21st Century Manufacturing & Design*', '*Engineering to Improve Operations of Manufacturing Enterprises'*, and the upcoming 'Making Value' workshop [NAE, 2009; 2011; 2012]
- **Leading manufacturing universities**, notably the Massachusetts Institute of Technology's which is carrying out a substantial study of *'Production in the Innovation Economy' [MIT, 2012]*

Germany: The Federal Government carries out regular, systematic, and inclusive analysis of manufacturing trends, challenges, emerging production-related research fields and priorities, for example the analyses underpinning the German Ministry for Research & Education (BMBF) 'Framework Concept for Tomorrow's Production' [BMBF, 2007], national foresight exercises of 'Future Research Fields' and the BMBF-

[2] In the course of this study, we were only able to identify a relatively small number of recent governmental foresight analyses of manufacturing (broadly defined*).* In order to verify that we were not missing important studies we engaged with a number of international manufacturing experts and academics, as well as contacts from the Foreign & Commonwealth Office's 'Science & Innovation Network' (SIN). Feedback received suggests that not only is there relatively little available in the public domain and/or in English, but that there have been very few manufacturing foresight studies. Further details of feedback received from international contacts can be found in Appendix 2.

commissioned study 'Production Research 2020' [Abele, 2010; 2011]. German activities exploring the future of manufacturing have been carried out by a variety of stakeholders including:

- **Confederation of German Industries,** which carried out a recent analysis of value creation in '*Germany 2030*' with significant attention paid to manufacturing trends [BDI, 2011]
- **German Academy of Science and Engineering,** which has working group analysing on '*Sustainable value-added [production] networks for tomorrow's markets*' [Acatech, 2010]
- **Leading manufacturing technical universities**, notably the RWTH Aachen 'Cluster of Excellence for Integrative Production Technology for High Wage Economies', which has carried out roadmapping analyses of technologies with the potential to underpin future manufacturing competitiveness [Brecher, 2012]

Other Manufacturing Economies: In the course of this study we were only able to identify a relatively small number of recent governmental foresight analyses of manufacturing. These studies were carried out by an eclectic range of stakeholder organisations which varied from country to country, for example: The Indian National Manufacturing Competitiveness Council; the Canadian Manufacturers & Exporters (CME); the Association of Swedish Engineering Industries (together with the Swedish Production Academy and the RTO Sverea IVF); the Japanese Ministry of Economy, Trade and Industry; and the Chinese Academy of Sciences. As discussed above, these studies have significant variations in emphasis as well priority focus areas specific to their national contexts. For example, Australian analysis of the future of manufacturing pays particular attention to issues related to natural resources and the Chinese market. Since the 2011 Tōhoku earthquake, Japanese analysis of the future of manufacturing has paid particular attention to the potential impact of earthquake damage to manufacturing supply chains.

Multinational organizations: In addition to national analyses, there are also a number of interesting multilateral initiatives which have also explored aspects of the future of manufacturing. **The EU Commission's 'ManuFuture' initiative** - an industry-led 'European Technology Platform' – carried out substantial analyses of the future of European manufacturing (with an emphasis on high-added-value products, processes and services), including the development of roadmaps and identification of associated technology objectives and priorities [Jovane, 2007]. **The Intelligent Manufacturing Systems consortium** (IMS) – an industry-led, international R&D programme - has mapped and analysed ongoing manufacturing research activities and foresight analyses to identify manufacturing research priorities for 2020 [IMS, 2010]. **The World Economic Forum** initiated a '*Future of Manufacturing Project*' in 2011 exploring future trends; strategies for manufacturing firms to respond to a changing manufacturing 'ecosystem'; and modes of government-industry engagement to address future challenges [WEF, 2012].

1.3 Report outline

Section 2: Manufacturing Systems: Definitions and Dimensions
In this section, we highlight a number of international perspectives on the nature and definition of manufacturing (and related terms). In particular, we highlight the systems nature of manufacturing; the variations in definitional emphasis reflecting national

industrial and innovation system contexts; and the implications for the structure of foresight analyses.

Section 3: Manufacturing Foresight: Tools, Methodologies & Practices
This section gives a brief overviews of methodologies deployed in high profile international manufacturing foresight exercises, including: targeted surveys and Delphi; literature surveys; solicitation of input from stakeholders (including white papers, etc); expert panels and working groups; workshops, symposia and summits.

Section 4: Future of Manufacturing: Trends, Capabilities, Value & Priorities
This section reviews some of the broad 'framework' themes considered in many international foresight exercises, in particular: Trends and drivers; challenges to competitiveness; manufacturing capabilities; value creation (and capture); and related research & innovation **priorities and other policy themes.**

Section 5: Concluding Observations
This section summarises some of the key themes that emerged from this review of international manufacturing foresight-related exercises. In particular, we highlight approaches which may be worth adopting or adapting within the current UK '*Future of Manufacturing*' foresight study.

2. Manufacturing systems: definitions & dimensions

In this section, a number of international perspectives on the nature and definition of manufacturing (and related terms) are outlined. The manufacturing-related definitions, terminology and themes are drawn from international analyses related to the future and importance of manufacturing, as well as selected academic literature and the publications of manufacturing-related stakeholder organisations.

There are significant variations in terminology and definitional emphases in the international foresight analyses reviewed in this study, reflecting differences in stakeholder perspectives, national innovation system and industrial contexts, and responses to the changing nature of manufacturing itself. Many foresight-related exercises – in order to address the complexity associated with the systems-nature of manufacturing – make particular efforts to distinguish between different categories of manufacturing system elements (and subsystems). This section gives a brief overview of the following:

- Commonly used definitions of 'manufacturing' (and related terminology)
- International variations in manufacturing terminology
- Key system elements included in manufacturing-related conceptual frameworks

2.1 Definitions of manufacturing and related terminology

There are significant variations in both emphasis and scope in the manufacturing terminologies used within different nations and by different stakeholder types. There appear, however, to be some common trends, in particular more recent definitions often highlight (a) **the systems-nature** of global manufacturing, modern industrial technologies, production supply chain networks, etc; and (b) particular technological and/or organizational enablers that are **sources of competitive advantage**.

There also seems to be consensus that, because of the changing nature of manufacturing systems (and complex interdependencies between system elements), that foresight-related definitions of 'manufacturing' should be relative flexible and inclusive. Some of common variants of the term 'manufacturing' are discussed below, in order of increasing definitional scope.

Traditionally, manufacturing has typically been defined in terms of the process of transforming materials into useful goods and is still used in this way in certain contexts.

Sometimes such definitions are further clarified by identifying the establishments engaged in the 'manufacturing sector'. Although it is generally acknowledged that the boundaries of manufacturing and other sectors can be 'somewhat blurry' [NAICS, 2007].

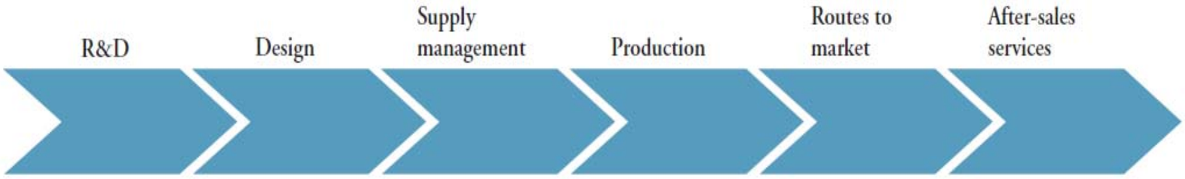
> *Manufacturing: The process of converting materials into usable products through human skill and knowledge.*
>
> Working definition for the National Academy of Engineering's, *Making Value Workshop*, June 2012

> *The manufacturing sector comprises establishments engaged in the mechanical or chemical transformation of materials substances, or components into new products.*
>
> *Establishments in the manufacturing sector are often described as plants, factories, or mills and characteristically use power-driven machines and materials-handling equipment... Manufacturing establishments may process materials or may contract with other establishments to process their materials for them. Both types of establishments are included in manufacturing.*
>
> North American Industry Classification System, 2007

Other definitions of 'manufacturing' emphasise the different phases of the journey of a manufactured good from raw materials to final product.

> *'...a system designed to perform activities required to deliver end-product to the customer and meet their needs, from design to finance, production to sales, marketing, after-sales service...'*
>
> US Department of Commerce (2004)

Figure 2.1: Schematic representing simplified production-based industrial value chain



Such definitions are sometimes designed to highlight the different ways that value can be added, both upstream and downstream of factory-based activities. These different stages of the manufacturing are often represented in terms of a simple 'value chain' of activities.

> *'...a business system encompassing all activities required to deliver products that meet customer needs... extends from R&D, design, engineering, to production, finance, sales, marketing, and after-sales service... extends beyond any single enterprise, across increasingly global supply chains and business networks'*
>
> Canadian Manufacturers & Exporters (2005)

Some definitions also endeavour to highlight that manufacturing often takes place within a complex set of interacting supply chains and other relationships, and that new manufacturing enterprise models and configurations are emerging – notably the blurring of the traditional boundaries between 'manufacturing' and 'service' industries.

Several manufacturing foresight-related exercises highlight the distinction between the industrial value chains of (commodity based) 'consumer industries' and those of (capital equipment-based) 'factory supplier' sectors. In particular, many of the production system innovations necessary for future competitiveness (and economic value capture) are likely to come from production technology firms providing technological, system or process solutions in response to the needs of ‘consumer industries’.

Figure 2.2: The Enabler Role of Actors in (Capital Intensive) Manufacturing Sectors [Westkaemper, 2010]

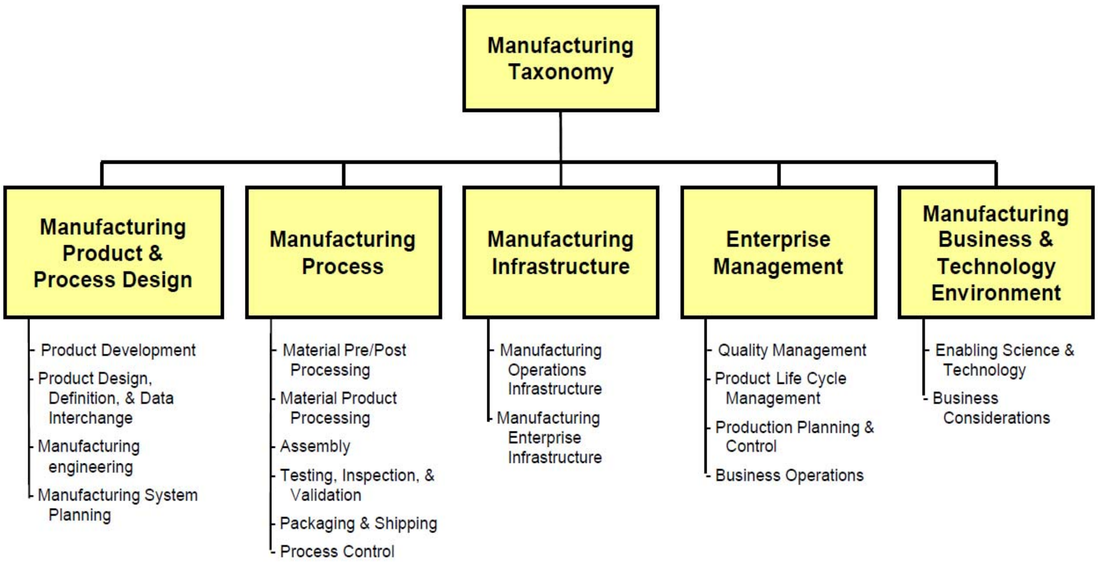
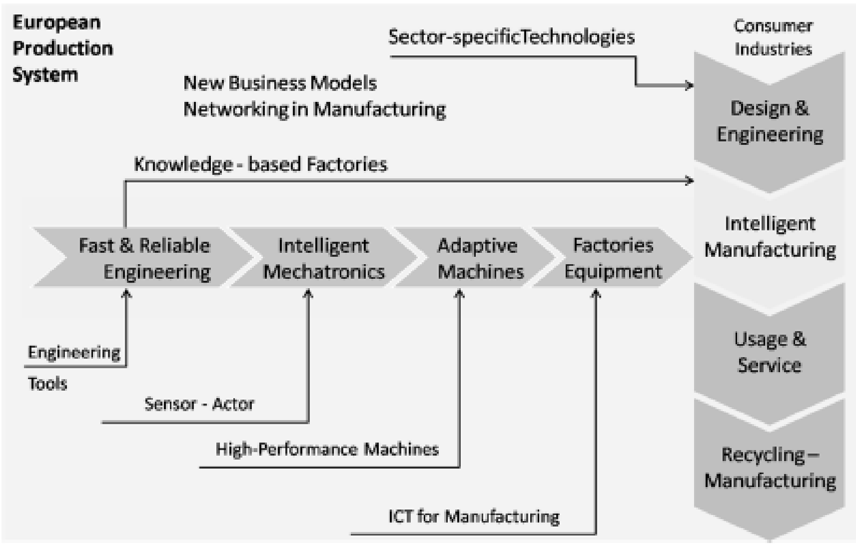


Figure 2.3: ‘21st Century Manufacturing Taxonomy: A Framework for Manufacturing Technology Knowledge Management’ [IMTI, 2003]



Not only are many of the most important modern high tech products themselves systems, but their manufacture relies on a range of industries contributing and integrating components, production systems, service systems, etc. Some studies of the future of manufacturing endeavour to articulate manufacturing ‘taxonomies’ which distinguish between different types of process, infrastructure, management activities and enabling factors. A commonly cited taxonomy, for example, is one developed by the *Integrated Manufacturing Technology Initiative* illustrated in Figure 2.3.

2.2 International variations in manufacturing terminology

Manufacturing-related definitions and terminology vary from country to country, reflecting national industrial strengths and/or perspectives of key stakeholders within national innovation systems.

- **Advanced manufacturing:** In the United States, the discourse on manufacturing is dominated by discussion of 'advanced manufacturing' often highlighting the importance of manufacturing IT systems or emerging science-based technologies
- **Monozukuri:** In Japan the term 'monozukuri', although often offered as a direct translation for 'manufacturing', has a particular emphasis on the importance of high quality craftsmanship, design and integration engineering
- ***'Produktionssysteme und -technik'*****:** in Germany typically emphasises production technologies, machine tools and factories

The following is a brief overview of these different national definitions (and related terminologies), as well as national perspectives on sources of competitive advantage and economic value capture from manufacturing.

2.2.1 Advanced manufacturing

A recent report for the US President's Council of Advisors on Science & Technology defines advanced manufacturing as:

> *'The family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical / biological sciences, e.g. nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies'*
>
> President's Council of Advisors on Science & Technology (2011)

There are, however, significant variations of scope and emphasis among stakeholders regarding how 'advanced manufacturing' is defined. The white papers prepared by the Science & Technology Policy Institute (STPI) for the President's Council of Advisors on Science & Technology [STPI, 2010] contain a useful discussion of these variations in definitional emphasis for the term 'advanced manufacturing' in the United States:

- **Use of New Methods to Produce Newer or Better Products** – i.e. defined in terms of the '*how to*' of production: the use of high precision technologies and ICT integrated with a highly skilled, high-performance manufacturing work force
- **Manufacturing in New Industries –** i.e. definitional distinction emphasising new and emerging industries (as opposed to traditional sectors, e.g., automotive and steel industry, which are typically characterised by their low cost high volume nature)
- **S&T-Based Manufacturing –** a particularly US emphasis distinguishing those approaches to manufacturing which involve the translation of novel science and technology into manufacturing processes, technologies and products
- **The Frontier of Advanced Manufacturing –** an approach to defining advanced manufacturing which emphasises advances which lead to decreased costs or increased productivity (and economic value captured), whether arising from traditional, new or S&T-based sectors. The term *frontier* intended to emphasise the evolving nature of advanced manufacturing and where value can be captured

Advanced manufacturing: systems, products & sources of innovation

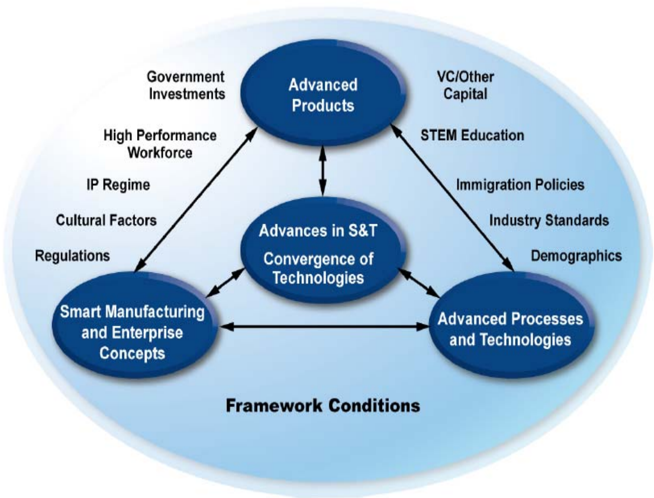
The recent review of '*Emerging Global Trends in Advanced Manufacturing*' by the Institute for Defense Analysis (IDA, 2012) contains an extensive review of definitions of 'advanced manufacturing' in the academic industry practitioner literature. The IDA report also offers a broad synthesis definition that captures several dimensions of the term as used by different stakeholders:

> *'Advanced manufacturing improves existing or creates entirely new materials, products, and processes via the use of science, engineering, and information technologies; high-precision tools and methods; a high-performance workforce; and innovative business or organizational models.'*
>
> Institute for Defense Analysis (2012)

The IDA report proposes a framework – one that is intentionally broad, in order to account for the wide range of perspectives – which is designed to highlight that advanced manufacturing may involve one or more of the following elements:

- **Advanced products** (typically technologically complex products, new materials, products with highly sophisticated designs)
- **Advanced processes and technologies** (new way of accomplishing the "how to" of production)
- **Smart manufacturing systems and enterprise concepts** ("smart" systems extend beyond the factory to include enterprises creating and using data throughout the product life cycle with the goal of creating processes that respond rapidly to changes in demand)
- **Advances in S&T** (breakthroughs in science, computational modelling and power are drivers for advanced manufacturing)

Figure 2.4: Institute of Defense Analysis framework illustrating the multifaceted nature of 'advanced manufacturing' [IDA, 2012]



The STPI framework also identified 'key framework conditions' – factors with the potential to support the advancement of manufacturing capabilities and future competitiveness, e.g. government investments, high-skilled workforce, IPR, cultural factors, regulations, venture capital, STEM skills, industry standards, demographics and immigration policies. See Section 4.3 on enablers and success factors.

2.2.2 Monozukuri

In Japan "manufacturing" is often translated as "monozukuri". This direct translation, however, does not convey the full sense of a uniquely Japanese concept. In Japanese, the words mono (thing) and zukuri (process of making), when taken together literally mean the process of making things. In particular, monozukuri contains an almost spiritual sense associated with the desire to craft excellent products and an ability and pride in constantly striving to improve a production systems, processes and craftsmanship.

> **Monozukuri:** *Meticulous product development through skilled use of teamwork and collaboration.*
>
> *Traditionally, associated with material processing and/or mechanical production activities (often carried out by SMEs) in which Japan has excelled, monozukuri places an emphasis on crafting excellent products and constantly striving to improve production systems, processes and craftsmanship.*

Despite some suggestions that this sense of monozukuri is in fact a relatively modern concept [Tsai, 2006] which has been promoted to address the perceived de-industrialization of the Japanese economy, monozukuri is, nevertheless taken very seriously and features prominently within national science & technology policy initiatives. Increasingly, policy-makers and academics are adopting an extended definition of Monozukuri which encompasses an extended product development flow – from research and testing through planning, prototyping to manufacturing, distribution, and maintenance, all the way to recycling/end-of-life management. According to Professor Takahiro Fujimoto, Director of Monozukuri Management Research Centre at the University of Tokyo, "monozukuri" describes not only physical production activities, but also product development and the processes by which products reach shelves – a broader term for the total value creation generated from the extended process.

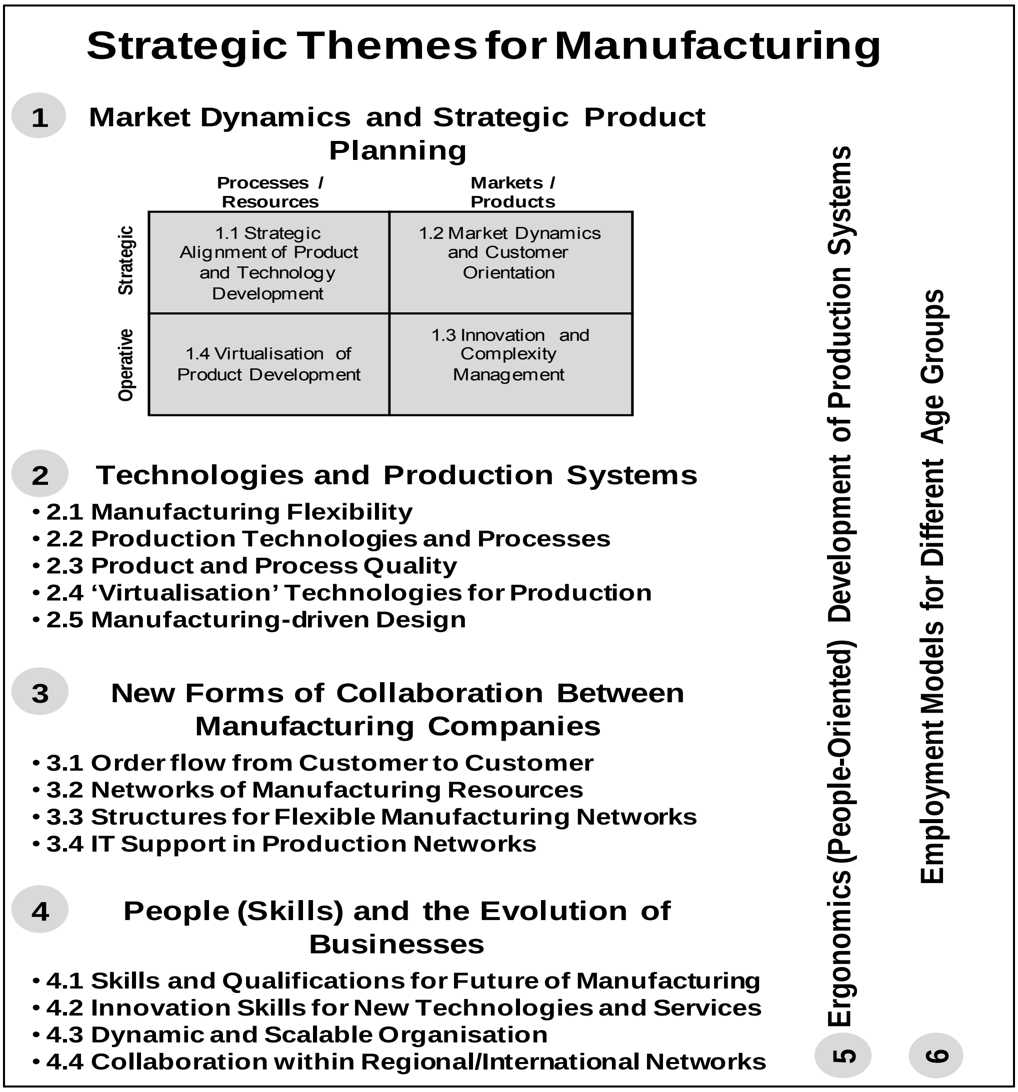
'New Style' Monozukuri: This thinking is also reflected in the concept of a 'new Style of Monozukuri' proposed by the Japanese Association of Corporate Executives, which – in addition to traditional strengths in terms of attention to detail – emphasises: the pursuit of more advanced technologies; the capture of more diverse markets; addressing trends such as environmental issues; and responding to increasingly complex manufacturing systems.

Kotozukuri: The Japanese discourse and debate regarding the definition and scope of 'manufacturing' has recently started to include the concept of 'Kotozukuri'. Kotozukuri, by contrast with traditional Japanese manufacturing which – according to some commentators - overly focused on product performance and reliability, refers to a business approach to production that has much more of a market-perspective on the production in order to ensure that products (and associated services and business models) meet the demands of customers in increasingly diverse markets.

2.2.3 Production technology

The German Ministry for Education and Research prioritises its funding of manufacturing related R&D according to analyses based on their "*Framework concept for Research for Tomorrow's Production"* [BMBF, 2007]. The focus of this programme is to ensure the innovation needs of Germany's manufacturing enterprises (with particular attention paid to the needs of SMEs) are addressed; and that research findings are translated effectively and efficiently into new processes, technologies and applications. The framework concept is revisited on a regular basis – in cooperation with manufacturing experts in firms and research institutions, industry associations and trade unions - to identify the most important manufacturing research challenges relevant to the future competitiveness of Germany's industrial base.

Figure 2.5: Framework Concept for Research for the Production of Tomorrow [BMBF, 2007; Cummins, 2010]



The "*Framework concept for Research for Tomorrow's Production*" has four key action areas to support manufacturing competitiveness:

- Market dynamics and strategic product planning (further characterised in terms of relevance to operational or strategic issues relevant to process/resource or products/markets)
- Technologies and production systems
- New forms of collaboration between manufacturing firms
- People (skills) and the versatile company

These themes (and associated sub-themes) are illustrated in Figure 2.5 [BMBF, 2007; Cummins, 2010].

2.3 Manufacturing systems: elements, subsystems and configurations

Many manufacturing foresight-related exercises make particular efforts to distinguish between different categories of manufacturing system elements (and subsystems). Notable examples include:

- **Different types of manufacturing firms**, in particular factory equipment makers (capital goods) and factory users (consumer goods)
- **Different manufacturing 'enterprise functions'** (firm-level value chain stages): innovation processes and product development; production techniques and machines; service and usage; business models; logistics and planning; skills and workforce demographics.
- **Established and emerging sectors** (manufacturing-based)
- **SMEs and MNCs:** Small & Medium Sized Enterprises and major manufacturing firms (which have significant influence within value chains, global awareness and research insights)
- **Manufacturing R&D:** Types of research activity with the potential to advance different manufacturing capabilities (unit process technologies, machine level technologies, manufacturing enterprise systems, etc)
- **Production activities for high wage economies:** Manufacturing concepts and approaches to production with potential to underpin competitiveness (and value capture) in high wage economies

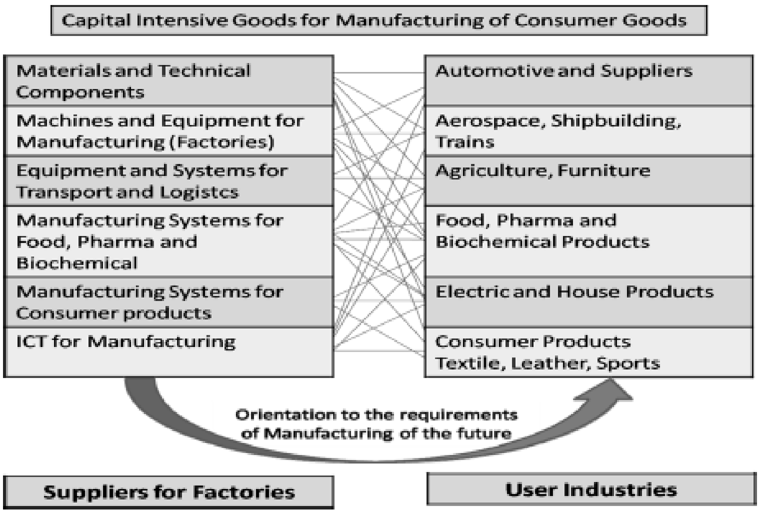
These different 'dimensions' of analysis are discussed in more detail in the remainder of this section and/or in the discussion of strategic priority policy themes at the end of this report.

2.3.1 Manufacturing sectors: factory equipment makers and factory users

A number of high profile manufacturing foresight-related exercises [Abele, 2010; Jovane, 2007; KET, 2011] have particularly emphasised the important distinction between industrial engineering-based manufacturers of capital intensive production-related goods and services and ‘user’ consumer product industries, i.e. between:

- **Factory equipment makers:** Manufacturers of capital intensive goods and services, who produce and deliver material, component machines, systems and equipment for manufacturing: Machine tools; prototyping tools; robotics, assembling and handling technology; measurement and testing equipment; packaging machinery; drive technology; pumping technology; etc
- **Factory users:** Manufacturers, who produce products for consumer markets: aerospace; automotive; chemicals; pharmaceuticals; metal products (including automotive suppliers); power generation; medical technologies and devices; etc.

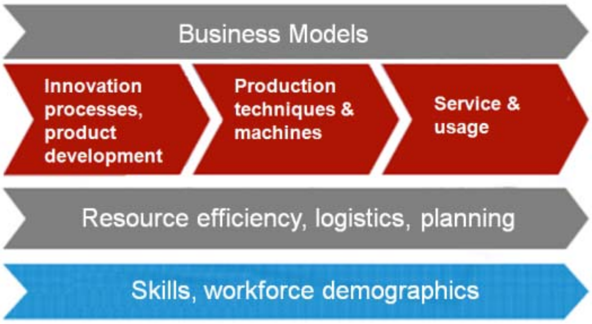
Figure 2.6: Schematic illustrating the distinction and interactions between different ‘supplier’ and ‘user’ manufacturing industries [Jovane, 2007]



2.3.2 Manufacturing enterprise functions

Many of the ‘Future of Manufacturing’-related studies explored in this report examine the implications of the trends and drivers for different themes related to the functioning of manufacturing enterprises. For example, the *ProduktionForschung2020* [Abele, 2010; 2011] study explored the impact of identified ‘mega-trends’ on the manufacturing ‘enterprise functions’ illustrated in Figure 2.7. Working groups, associated with each of these themes, were set up to identify appropriate actions to address these challenges, as well as associated research and innovation needs, and then prioritise research needs.

Figure 2.7: Schematic illustrating themes used to structure analysis of the impact of manufacturing trends and drivers on the activities of manufacturing-related enterprises [adapted from Abele, 2010]



2.3.3 Emerging sectors (and established sectors)

Many of the international manufacturing foresight studies reviewed in this report make a particular effort to address the different ways 'megatrends' and drivers influencing future of manufacturing will impact emerging industries as opposed to established sectors; and the implications for future value creation (and capture).

In particular, emerging sectors based on novel science and technology will face particular 'manufacturability' challenges. Emerging technologies (including novel materials) may also have significant implications for new production technologies and processes, with potential challenges and opportunities for established sectors. Analysis by the Advanced Manufacturing Systems Working Group of EU Commission's High Level Group on Key Enabling Technologies highlights the potential of advanced manufacturing systems to turn promising emerging technologies into value for society [EU, 2010].

2.3.4 Small and Medium-sized Enterprises (SMEs)

Most of the international foresight studies reviewed in this report paid particular attention to the future challenges and opportunities facing manufacturing-based SMEs. Significant care was taken to understand the implications of key trends and drivers for SME competitiveness and the consequences in terms of their innovation and infrastructure needs. In many cases considerable effort was spent ensuring the SME stakeholders – and not just large powerful firms – were engaged with in a systematic and thorough way. Indeed some foresight exercises, for the example the '*Future of Manufacturing*' study carried out by Stanford Research Institute on behalf of the National Institute of Standards & Technology [SRI, 2004], were entirely focused on the future of manufacturing for SMEs.

Small and medium-sized enterprises were also an important focus for several policy-related priorities identified by manufacturing foresight studies. Strategic priority policy themes related to SMEs are discussed in more detail in Section 4.5.2.2.

2.3.5 Production capabilities for high wage economies

As discussed in section 1.1, a key feature of many recent manufacturing foresight studies is an emphasis on sources of economic value capture from production activities. This is of particular concern in high wage economies with a strong manufacturing base. In Germany, the high profile '*Cluster of Excellence for Production Technologies in High*

Wage Countries' [RWTH, 2010] has identified four distinct 'integrative production' capabilities which have the potential to underpin manufacturing competitiveness in high wage economies [Klocke, 2009]. In particular, the Aachen group have distinguished between approaches to production which have the potential to allow for greater variability of products while at the same time being able to manufacture them at cost-levels close to that of mass production. They argue that such approaches offer opportunities for high wage economies to retain high value production activities in the face of competition from low wage economies.

These categories of activity, which have been used to structure roadmapping analyses of future manufacturing technologies [Schuch, 2011], include:

- **Individualised production:** A manufacturing concept whereby entire production systems are configured to enable high product variety with manufacturing costs approaching mass production levels. Key approaches to this endeavour include: *modular products*; *rapid manufacturing*; and *customised mass production processes*
- **Virtual production:** An approach to manufacturing designed to address challenges associated with decentralised parallel product and process development, supporting simultaneous product and process development planning with sophisticated simulation and data management. Different aspects of this approach include: *material and process simulation*; *technology planning*; *machinery and control simulation*; *factory planning*; *product planning.*
- **Hybrid production:** Hybrid production involves the integration of production technologies into systems which, while more complex, can shorten or simplify value chains and/or enable novel processing. Hybrid production system approaches can involve: *hybrid machines; combined process steps;* and *hybrid products*
- **Self-optimising production: '**Self-optimising' production approaches involve technologies which enable responsiveness and adaptation to evolving value capture opportunities, goals and conditions. Key technologies and organizational innovations involved in 'self-optimised' production include: *Software and control; 'intelligent' manufacturing hardware; novel 'human & organisational'* concepts and structures.

2.3.6 Manufacturing R&D

Many of the manufacturing foresight exercises identified in the course of this review were primarily designed to identify manufacturing-related research and innovation priorities. A number of these exercises make efforts to categorise different types of manufacturing-related research. For example, a report by the US National Science & Technology Council's the Interagency Working Group on Manufacturing R&D [NSTC, 2009] defined manufacturing research in terms of its potential to advance any of the following:

- **Unit process-level technologies** that improve manufacturing processes, such as machining, deposition, layering, moulding, or joining
- **Novel process-level technologies**, such as those required to manufacture heterogeneous 3D nanotechnology products
- **Machine-level technologies and systems** that improve manufacturing productivity, quality, flexibility, or safety for such tasks as fabrication, assembly, or inspection
- **Systems-level technologies for innovation in the manufacturing enterprise** (e.g. controls, sensors, RFID, and ICT); technologies that support logistics and transportation pathways and infrastructure; and methods and approaches that improve design and decision-making and integrated and collaborative product and process development

- **New knowledge that advances workforce abilities, sustainability, or manufacturing competitiveness**; anticipates and responds to global labour, health and safety, and environmental objectives; anticipates and responds to global and domestic availability of energy and materials; and informs supporting investments in energy, communication, information infrastructures.

Such categorization is considered useful in more carefully structuring foresight analysis of promising manufacturing-related emerging technologies and future research domains; and in identifying R&D priorities for addressing the innovation needs of the manufacturing systems of the future, as discussed in see Section 4.5.

3. Manufacturing foresight: methods & practices

The international studies of the future of manufacturing reviewed in this report used a broad range of methodologies. The approaches used were mainly qualitative (e.g. surveys, expert panels, interviews, etc.) or semi-quantitative (e.g. Delphi, technology roadmapping, etc.). Many studies used a mix of methodologies, combining engagement with key experts with broader interactions with manufacturing stakeholder communities, backed up by 'desk research' analysis of the existing evidence base. This section gives an overview of the variety of methodologies deployed in recent high profile international studies of the future of manufacturing.

The mix and type of methods found in the manufacturing foresight exercises examined in this report reflect the academic analyses of how foresight studies are used more generally [Popper, 2008]. International manufacturing-related foresight studies have been conducted using a variety of different approaches including:

- Literature Reviews (evidence surveys including, but not limited to, analyses of international manufacturing foresight exercises)
- Solicitation of input from stakeholder communities (including online 'public forums')
- Surveys (of various types and emphases, including Delphi and SME-specific surveys)
- SWOT Analysis
- Roadmapping
- Expert Panels and Working Groups
- Workshops, Symposia and Summits (including satellite meetings of established events)
- And, to a lesser extent:
- Case study analysis (e.g. exploring the implications for manufacturing of key emerging technologies)
- Scenario planning
- Bibliometric, patent and research funding analysis

As with foresight analysis more broadly, the selection of methods varies by country and stakeholder group [Popper, 2008]. This reflects a variety of factors, such as: the scale and scope of study (transnational, national, regional); the dominant manufacturing sectors and industrial structures within the economy; the time horizon of study; the missions and perspectives of the study sponsors; the innovation strengths and R&D intensity of the nations conducting exercises.

In addition to identifying illustrative examples of the use of particular methods, this report highlights a number of selected studies which used a range of methodologies in combination (appropriate to the different perspectives and goals of the lead organizations).

3.1 Literature review

Literature reviews are frequently conducted as part of foresight exercises whatever their scope and scale. They are often used as part of the initial scanning process and to formulate and set the direction of the foresight work. In some foresight exercises the literature review concentrates largely on the regional context focusing for instance on the national position. Other exercises take a much broader view and try to capture, and understand, what work has been undertaken in other countries and what lessons might be learnt.

One of the more comprehensive analyses of manufacturing foresight studies carried out in recent years was by carried out by TNO for the European Commission's Future of Manufacturing in Europe Initiative [van der Zee, 2007], summarised in the report ‘Manufacturing Futures of Europe: A Survey of the Literature’. This review focused on previous European foresight/future studies but also considered similar projects in America and Asia. Asian studies on the future of manufacturing available in English were found to be sparse. The review also considered three global future studies that had a primarily economic focus (2007 study by the World Bank on *Global Economic Prospects*, and two studies on emerging economies Goldman Sachs 2003 and PWC 2006 – these types of report were outside the scope of the current exercise.) The literature review was conducted to identify likely trends and drivers affecting the future of European Manufacturing and to take account of similar work in the US and Asia.

The most recent review of literature and foresight studies was carried out by the US Institute for Defense Analyses as part of their study of ‘Emerging Global Trends in Advanced Manufacturing’ [IDA, 2012]. This was an extensive review that included a comprehensive analysis of government documents from the EU, Germany, the UK, Japan, China, South Korea, Taiwan and Brazil and considered long-term government plans to provide insight into strategic priorities. The review also incorporated a substantial review of definitions of advanced manufacturing. This extensive work was used as a platform for a series of interviews with industry, academic, and government experts recognised as leaders in their fields.

3.2 Knowledge input from manufacturing stakeholder communities

There are many reasons why almost all foresight exercises engage with stakeholder communities throughout the exercise, including:

- To simply understand what work already exists and what ‘futures’ work stakeholders themselves may already have undertaken (e.g. recent Automotive Council roadmapping and research challenges exercise);
- To confirm drivers/challengers, capabilities, and understanding of value capture;
- If at any point a decision is to focus on specific sectors this allows sense checking that what applies in one sector has read-across to others; and, ensures that parallels can be drawn and final observations can be made relevant to a broad community;
- To help sense check/validate direction of future work; and,
- To ensure that foresight project is not abstract but grounded in reality and can be understood by the widest community.

Possible approaches to engaging with stakeholders could include:

- One-off surveys
- Delphi
- Solicitation
- Engagement in expert panels/working groups
- In-depth interviews with known experts
- Workshops at events

Whatever tool(s) is used to capture stakeholder knowledge this can be designed to enable analysis of information in a number of different ways (i.e. by identifying whether stakeholders are representative of SMEs vs large corporations, or traditional vs emerging sectors, regions etc.).

3.2.1 Delphi surveys

The Delphi method characteristically obtains independent inputs from groups of individuals through an anonymous, iterative survey with controlled feedback after each iteration. The method is widely considered to be effective in situations where no hard data exist and the primary source of information is well informed, learned opinion. They have often been used as a tool to collect a wide range of opinions as a base for further debate. The advantage of the approach is its ability to collect a large amount of information in a structured form.

A Delphi survey was used to great effect in underpinning an older, but well regarded, study by the US National Research Council of Visionary Manufacturing Challenges for 2020. The questionnaire was designed and trialled at a *Workshop on Methods for Predicting Manufacturing Challenges*. The first questionnaire was to elicit information on participants' visions of:

- the competitive environment in 2020,
- characteristics of manufacturing enterprises in 2020,
- the challenges that would be faced by manufacturing enterprises, and
- the technological developments that would enable manufacturers to meet the challenges.

The questions called for open-ended responses to encourage creative thinking on the part of respondents and to ensure that the scope of survey responses was not limited to the committee's knowledge and thinking

Significant attention was paid to identifying survey participants. Recommendations were also requested from national and international industrial and academic manufacturing organizations and other stakeholder bodies, e.g. ASM International, the Council on Competitiveness, the Fraunhofer Society of Germany, the Industrial Research Institute, the Institute of Electrical and Electronics Engineers (IEEE), the International Institute for Production Engineering Research (CIRP), Intelligent Manufacturing Systems (IMS), the National Association of Manufacturers (NAM), the Society of Manufacturing Engineers (SME), the National Science Foundation (NSF), etc.

The criteria for selecting participants included manufacturing expertise and evidence of visionary thinking. Special efforts were made to contact a large number of international and industry participants.

The second follow-up questionnaire used (as part of the iterative Delphi method) provided participants with feedback on the results of the first questionnaire. Lists of manufacturing challenges and enabling technologies generated by the first questionnaire were used to construct the first two questions of the second questionnaire, which asked respondents to:

- indicate the challenges and technologies considered most important.

Two additional questions were added asking respondents to list:

- research topics based on prioritised enabling technologies and,
- the manufacturing challenges that would be addressed by these technologies.

The responses from the second questionnaire were collated to determine the manufacturing challenges and enabling technologies that the respondents considered most important.

A Delphi survey was also undertaken as part of the European ManVis project [Manvis 2005] this involved collecting the views of over 3000 European manufacturing experts from 22 countries. The survey was complemented by views of stakeholders and overseas experts collected at workshops and in interviews. The results and their impacts on industry and policy making were discussed at a Final Conference in 2005 and ultimately fed into the over-arching 'ManuFuture' Programme.

3.2.2 Open solicitation of input from communities

In addition to more targeted surveys or formal methods such as Delphi, there is also evidence of more open solicitation approaches being used. These have become more common with improvements in IT and the capability to conduct Web-based solicitations. They are a relatively low cost method to gather views and information on a subject. Some of these solicitation exercises are targeted towards specifically identified groups while others are publically open fora.

The US National Institute for Standards & Technology, as part of its Technology Innovation Program (TIP), recently solicited manufacturing-related white papers related to '*Accelerating the Incorporation of Materials Advances into Manufacturing Processes*' [NIST, 2009] and '*Manufacturing and Biomanufacturing: Materials Advances and Critical Processes*' [NIST, 2010]. As part of this process, NIST sought input regarding potential challenges in manufacturing from federal agencies and national advisory bodies (e.g. the National Science Foundation, National Research Council, the National Academy of Sciences, and the National Academy of Engineering), the Science and Technology Policy Institute (STPI), and a range of representatives of industry and academia. The White papers that came through in this way were then fed into a larger and longer term study.

As part of the recent study by the US President's Council of Advisors on Science & Technology on 'Ensuring American Leadership of Advanced Manufacturing' [PCAST, 2011] a broad range of views, expert and non-expert, were solicited. Over a period of several months, PCAST gathered information from experts in industry, academia, government agencies, and nongovernmental organizations via a workshop and a Web-based system for stakeholder input. In addition PCAST had an online 'Public Forum' soliciting public input on questions regarding the future of advanced manufacturing in the United States. The questions were broad in range and sought opinion on federal government policy, including

- **Support for new manufacturing technologies** (e.g. Are public-private partnerships, in which government jointly funds projects with industry and often academia, a good mechanism to support new manufacturing technologies that are beyond the reach of individual firms?).
- **Support for new manufacturing firms** (e.g. should the federal government assist in the formation and advancement of small firms in the advanced manufacturing sector?).
- **Support for existing manufacturing firms** (e.g. should the government generate an international benchmarking effort to compare US manufacturing infrastructures (i.e., technology platforms) with those of competing nations?)
- **A national manufacturing strategy** (e.g. should the President create a national science and technology based manufacturing strategy as a pillar of US economic policy?).

Following the study PCAST made a number of recommendations ultimately leading to President Obama's announcement in June 2012 of the creation of the 'Advance Manufacturing Partnership' (AMP). The AMP is a national initiative bringing together industry, universities, and federal agencies to identify opportunities for R&D investment, collaboration, and infrastructure for those emerging technologies with the potential to create high quality manufacturing jobs and support US manufacturing competitiveness[PCAST, 2011; AMP, 2012;].

3.2.3 Workshops, symposia & summits

Workshops, symposia and summits were frequently used as part of many of the foresight exercises explored in this report. Convening activities of different types were used to engage with, and gather input from, manufacturing stakeholders across a broad spectrum of perspectives.

Value of leveraging manufacturing community conferences: Several 'future of manufacturing' initiatives took advantage of opportunities afforded by established national and international conferences and other events to engage with particular stakeholder communities. There appears to be a perceived advantage in using existing stakeholder gatherings to engage more comprehensively (and often in a more participatory way) with a broader cross-section of stakeholders than might otherwise be involved in a foresight exercise-initiated events alone.
This approach was used, for example, in a study by the Swedish Production Academy. In 2007, as part of its collaboration with the Association of Swedish Engineering Industries, the Swedish Production Academy (Sweden's learned society of leading manufacturing research professors) used its annual Swedish Production Symposium to identify important emerging research domains and challenges, from its perspective – in particular research areas where Sweden has particular strengths and potential. These insights were added to information gathered by industry and national industrial research institutes to create a shared vision of 'Swedish Production 2020' intended as the basis for a manufacturing research strategy and priorities that would be needed to meet this vision [Teknikföretagen, 2009].

Identifying collaborative opportunities: In the case of joint academic-industrial forums, there are not only opportunities to match industrial manufacturing competitiveness challenges with potential solutions from the science and engineering research base, but there are potential added value opportunities to actually nurture public-private partnerships or individual collaborations. This type of approach has been adopted in a number of studies including: the NIST-hosted Interagency Workshop: *Extreme Manufacturing – What are the technology needs for long-term US Manufacturing Competitiveness?*

The 2011 workshop hosted by NIST reflects some of the key manufacturing research-related questions and themes of the US debate. The event was run by NIST in partnership with DARPA, NSF and NASA, thereby initiating a discussion forum for interagency initiatives. A key aim of the workshop was to identify crosscutting and enabling R&D investments needed by the federal government to build the innovation infrastructure for successful US manufacturing enterprises. It also aimed to begin to develop a long-term vision for manufacturing and to identify the technologies needed to reach this vision as well as the roadblocks to future success. Details of a number of additional workshops and symposia are provided in Appendix 1.

3.3 Analytical tools/techniques used in foresight studies

3.3.1 SWOT analysis

Exercises which address 'strengths, weakness, threats and opportunities' (SWOT) associated with aspects of manufacturing-related systems – whether economics, sectors, value chains, technologies, etc – are used in a variety of manufacturing foresight analyses. For example, the study by the EU high level group on key enabling technology 'Advanced Manufacturing Systems' synthesised other analyses to develop the SWOT analysis illustrated in Figure 3.1. This was, in turn, used to shape their policy recommendations designed to address the challenges and opportunities facing the future of manufacturing in Europe.

Figure 3.1: Example of future of manufacturing-related SWOT exercise. Table summarising outputs from analysis of European 'Advanced Manufacturing Systems' [EU, 2010]

Strengths	**Opportunities**
• Top class engineering tradition, expertise, know-how • Broad technology basis • Availability of a sound structure • Technological and manufacturing clusters • Cultural and manufacturing clusters • Cultural diversity in Europe	• To enhance technological leadership • To tap the potential of new (e.g. green industries) for growth and jobs creation • To provide top class education • To pioneer development for all industry
Weaknesses	**Threats**
• Costly research • Complex and bureaucratic R&D support structures • Investment risks for individual private partners high • Growing deficit of skilled staff • Costly up-scaling of processes • Innovation policies focused on end of value chains • Barriers to commercialization • Access to finance in capital markets • Fragmented European markets • Low labour mobility	• Globalisation • Application of precautionary principle when faced with new technologies • State-supported rise of new industries • Asymmetric conditions for trade in spite of WTO framework • Ageing society, lack of skilled workforce • Non-smart regulation • Investment in R&D in other regions brings leading edge of manufacturing to other regions

The Australian Future Manufacturing Industry Innovation Council's foresight analysis of '*Trends in Manufacturing to 2020*' [FMIIC, 2011] carried out a SWOT analysis for Australia's manufacturing base as a whole, highlighting many of the same themes, but also distinguishing between those SWOT factors that were impacting most countries and those of particular consequence for Australia's future manufacturing competitiveness.

3.3.2 Roadmapping

Roadmapping is used in two distinct ways in foresight studies. Existing roadmaps, often developed at an industry or sector level, are used as a foundation. They are often incorporated into broader literature reviews and help to provide an understanding of the current state of affairs and how it was reached. The existing roadmaps can also allow 'sense checking' of previous 'futures' work.

Roadmaps are also used towards the end of foresight projects acting as a bridge between foresight and planning to define medium to long-term action plans. See Schuh [*Technology roadmapping for the production in high-wage countries*, Schuh et al., 2011] for a discussion of the use of roadmapping in the context of manufacturing technologies and systems.

As part of the IDA study [IDA 2012] roadmapping by the Semiconductor Industry Association was used to present an industry-wide consensus on the R&D needs of the industry on a 15 year time horizon. Roadmapping was also used by the Chinese Academy of Sciences who, in 2009, published a 2050 roadmap for Chinese Science & Technology development [CAS 2009].

3.3.3 Case study/key sector analysis

It was beyond the scope of the foresight exercises explored in this study to systematically analyse the manufacturing-related issues associated with the future of all key technologies within all production-based sectors. Nevertheless, a number of international exercises did explore a limited number of technology-based case studies [IDA, 2012; STPI, 2012; EU KET, 2012]. These studies explore the future of manufacturing through more in-depth case studies of selected key technology areas. In particular, case studies are carefully chosen to illustrate the different ways that the landscape of advanced manufacturing might change over the time period considered by the foresight exercise (and the implications for the trajectories of new products, technologies, processes and business models, etc). Such studies typically took advantage of manufacturing-related insights gathered in previous analyses of the future of particular production-related technologies or sectors.

The choice of sectors is made in various ways e.g. contrasting a traditional sector and an emerging sector; technology domains which can have implications for manufacturing more broadly, etc. The Institute for Defense Analysis report [IDA, 2012], for example, gives a clear explanation on their rationale for choosing sectors.

The EU High Level Group on Key Enabling Technologies (KET) analysis of 'Advanced Manufacturing Systems' [EU, 2010] explored the role of advanced manufacturing systems within the future development of the other KETs (and associated emerging sectors):

- advanced materials
- biotechnology
- micro/nanoelectronics
- nanotechnology
- photonics

These enabling technology domains were chosen because of their potential as innovation platforms and the potentially critical role they could play in making new products and services affordable to the population at large.

The IDA analysis of 'Emerging Global Trends in Advanced Manufacturing' [IDA, 2012] included detailed exploration of the impact of global trends on four important, contrasting technology areas (two mature and two emerging):

- semiconductors
- advanced materials
- additive manufacturing
- synthetic biology

These studies take care not over-generalise case study findings, using the cases to illustrate important variations in what's driving manufacturing change; national capabilities and success factors are (sources of international competition); and how and where value can be captured. Typically, the cases have built on existing analyses (i.e. drawing manufacturing-related insights from prior technology-specific foresight exercises or sector-specific roadmaps).

3.3.4 Scenarios

A number of studies refer to the use of scenarios/scenario planning. A closer examination of what is meant by scenarios in these studies shows that this is taken to mean two very distinct approaches. Firstly, the term can refer to an approach that focuses on the development of narrative, often normative, scenarios which are then used as a tool to stimulate further discussion and debate. This is the most common use of scenarios in international studies. The second, less common, use of the term applies to where scenarios are developed and then modelled/quantified.

Examples of the first approach, with scenarios being used to stimulate debate, can be found in studies from Germany, Australia, Japan, the US and the EU. The point that these are largely narrative scenarios does not mean that these are simplistic or easy to construct. The development of the scenarios can be a complex and often iterative process: for example, in the European Commission sponsored project on '*The Future of Manufacturing in Europe 2015-2020'* (FutMan) where a set of four scenarios were developed [FutMan, 2003].

An example of the second approach, where scenarios are quantified, can be found in the study for the **European Commission by the Netherlands Bureau for Economic Policy Analysis** [Lejour, 2008]. A combination of literature review, creation of qualitative scenarios, and quantification of those scenarios were applied during the project, including:

- Review of existing studies used to identify the main trends and drivers: 101 foresight reports were examined with particular attention to EU projects (*FutMan, ManVis and Manufuture)*
- Five sets of drivers were identified and, from these, two 'moderate extremes' scenarios were developed based on: increasing integration of markets, and stalling or reversal of integration
- The scenarios sketched macroeconomic developments showing the possible impact of globalization, technology change, ageing, etc
- The final step was to quantify each of the scenarios using a recursively dynamic general equilibrium model, 'WorldScan' [LeJour, 2008; LeJour, 2006]
- Following quantification and assessment of the possible impacts of various trends, the project explored how such trends could be affected by policies.

3.3.5 Bibliometric, patent and research funding analysis

Relatively little evidence was found of the use of bibliometric, patent or research funding analysis in foresight-related exercises exploring manufacturing (broadly defined, i.e. non-technology- / sector-specific analysis).

The US Institute for Defense Analyses – as part of their study of 'Emerging Global Trends in Advanced Manufacturing' [IDA, 2012] – carried out analyses of governmental R&D investment in relevant technologies, as well as some bibliometric 'proof-of-concept' analysis to support identification of countries with highest manufacturing-related research intensities.

3.4 Selected manufacturing foresight exercises: exemplar studies

Many of the approaches described above are most often used in combination, using a portfolio of tools. The choice and diversity of approaches reflect both the specific aims of the studies and the amount of resource available (time and cost). Some key studies reflecting this diversity of approaches include:

- **The Future of Manufacturing,** an older study by Stanford Research Institute [SRI 2004] for the US Manufacturing Extension Partnership, which included particular analysis of small and mid-sized firms as well as including more quantitative analyses of macroeconomic data
- **Swedish Production 2020**, [Teknikforetagen, 2009] a challenge-focused exploration of the future of manufacturing, driven bottom-up by a collaboration between an industry association, academic society and national industrial research institute
- **ProductionForschung 2020,** a government commissioned study focusing on manufacturing research needs, carried out in a highly systematic way with significant wide-ranging stakeholder engagement [BMBF, 2010]
- **Emerging Global Trends in Advanced Manufacturing,** a very recent think-tank led study with a focus on international insights into the future manufacturing trends, which

included in-depth technology case studies as well as some bibliometric analysis and benchmarking of manufacturing-related R&D funding [IDA, 2012]

- **Production in the Innovation Economy,** an on-going study by a leading manufacturing research university, Massachusetts Institute of Technology, that challenges key preconceptions about the value of manufacturing within innovation economies [MIT, 2011-]

The mixed portfolio of approaches used in the studies listed above, and some other exercises referenced in this report, are illustrated in the table below.

Table 3.1: Methodologies used in selected manufacturing foresight-related studies

	Literature Reviews/ desk based research	Industry Input	Academic Input	Interviews	Surveys and Question naires	Events, Workshops and Symposia	Working Groups	Expert opinion	Biblio metrics	Case Studies	Public Fora
Swedish Production 2020	✓	✓	✓		✓	✓	✓				
BMBF: New Future Research Fields	✓	✓	✓	✓	✓	✓		✓	✓		
Production Forschung 2020	✓	✓					✓	✓	✓		
PCAST	✓			✓				✓			✓
Institute of Defence Analysis [2012]	✓	✓	✓	✓				✓	✓	✓	
CAS	✓		✓			✓		✓			
MIT PIE	✓	✓	✓	✓							

4. Manufacturing foresight frameworks: trends, challenges, capabilities, value, priorities

There are significant variations in the focus, scope and time horizons of many of the ‘future of manufacturing’-related studies reviewed in this report. As discussed in previous sections, these variations partly reflect different stakeholders involved, national industrial and innovation systems contexts and even definitions of ‘manufacturing’ itself. Furthermore, insights into the future of manufacturing can also be found in a range of other foresight-type exercises: emerging science & technologies (facing manufacturability challenges); production system technologies; individual industrial sector roadmaps; foresight studies exploring particular socio-economic challenges (where manufacturing capabilities have a role to play).

Whatever the motivation, scope, or focus of future-looking exercises, analyses of the ‘future of manufacturing’ identified in this review typically explore some or all of the following broad themes:

- Trends & Drivers: Common set of ‘mega-trends’; disruption from interplay between different trends (importance of systems approach to analysing future of manufacturing)
- Challenges: Challenges to the competitiveness of national manufacturing firms and manufacturing ‘ecosystems’ more generally
- Capabilities & Success Factors: Capabilities to meet challenges / opportunities presented by trends
- Value Creation: What elements (and associated configurations) of modern manufacturing systems have the potential to capture significant value for the local economy and/or contribute to social value creation (including ‘grand challenges’)
- Future strategic priorities: Priority actions to ensure necessary capabilities and infrastructure in place to ensure future manufacturing competitiveness and value capture; both research & innovation investment priorities as well as other strategic, often policy-related, priorities

This section explores different aspects of international analyses of the future of manufacturing relevant to these broad themes, including illustrative examples from important manufacturing economies.

4.1 Trends & drivers

4.1.1 Megatrends

There is significant commonality between the lists of trends and drivers of the future of manufacturing identified within the studies explored in this report. There is considerable consensus regarding the major *(non-sector-specific) global trends* – ‘Megatrends’ – with the potential to impact the competitiveness of the national manufacturing base. They include phenomena affecting industrial activity at large, such as the increasingly complex and globalised nature of manufacturing; the dramatic reduction in manufacturing timescales associated with the acceleration of technological innovation; and the growing need for sustainable, resource-efficient production. ‘Megatrends’ typically fall into a number of broad headings including:

- **Globalisation** including: offshoring and outsourcing; ‘rising power’ economies; etc
- **Sustainability** including: resource- and energy-efficient manufacturing; carbon footprint, pollution, biodiversity; quality of life and consumption; etc
- **Demographics** including: changing patterns of international demand; individualism and customization; ageing society needs; ageing manufacturing workforce; ‘bottom-of-the-pyramid’ markets; etc
- **Urbanisation** including: mobility; urban factories; housing needs; etc
- **Threats to stability** including: natural disasters; defence sector manufacturing; terror threats; security technology systems manufacture
- **Accelerating product life cycles** including: increasing rates of technological innovation; increasing pervasiveness of technological innovation; manufacturability of emerging science-based technologies; novel S&T-based production technologies
- **Changing consumer habits** including: individualism; faster technological adoption

There are some international variations in those megatrends identified (or emphasised), depending on regional economic context, particular industrial strengths, stage of economic development, or the mission of the organisation carrying out the analysis. For example:

- Japanese studies on the future of manufacturing pay significant attention to an ageing **manufacturing workforce** [METI, 2011]
- Australian discourse devotes more analysis to issues of **natural resources** and the importance **of the Chinese economy** [FMIIC, 2011]
- The World Economic Forum includes national **industrial policy trends** among its key drivers [WEF, 2012], factors of direct relevance to many of the governmental and corporate leaders who participate in the forum.

4.1.2 Converging trends (in manufacturing)

In addition to identifying external drivers shaping the future of manufacturing, some studies highlight emerging trends in manufacturing practices which are a consequence of these external drivers. For example, the recent US study by the in Institute for Defense Analysis on ‘*Emerging Global Trends in Advanced Manufacturing*’ [IDA, 2012] points to a set of ‘converging trends’ associated with transition from labour-intensive production to high value production based on advanced technologies. In particular, the IDA analysis identifies five key trends based on their survey of leading US experts in academia, government, and industry:

- the ubiquitous role of **information technology**
- increasing reliance on **modelling and simulation** in the manufacturing process
- the acceleration of innovation in **global supply-chain management**
- moves toward **‘rapid changeability’** of manufacturing in response to customer needs and external impediments
- the acceptance and support of **sustainable manufacturing**

4.1.3 Trends influencing national value creation (and capture) in high wage economies

A recent study commissioned by the Federation of German Industries on '*Germany 2030: Future Prospects for Value Creation'* [BDI, 2011] highlights a range of trends influencing the potential of the Germany industries to create (and capture) economic value. Those trends highlighted for their potential to capture value in Germany's high wage economy included a set of manufacturing-related drivers, such as:

- Individualisation and personalisation of products and supply
- Automation of manufacturing process stages
- Digital integration of manufacturing processes
- New intelligent logistics concepts
- Increased use of materials with novel properties
- Continuing globalisation
- Reduction of production capabilities
- Changes in availability of raw materials
- Increasing importance of sustainability

Discussion of other trends influencing national value capture can be found in several recent initiatives related to the future of manufacturing [NAE, 2012; MIT, 2011; etc].

4.2 Challenges to competitiveness of national manufacturing firms

Several reports highlight the consequences of trends and drivers in terms of challenges to the competitiveness of manufacturing firms (within their particular national industrial-innovation system context). These challenges may arise from one particular trend or the interplay between several.

For example, the analysis of 'Swedish Production 2020' [Teknikföretagen, 2009] identified a set of challenges that Swedish industries would have to overcome to maintain their competitiveness. The challenges were matched by a set of manufacturing-related capabilities that firms would need to be successful in 2020:

- **Sustainable Production:** Manufacturing industries must achieve production sustainability from ecological, social, and economical perspectives
- **Flexible production:** Production processes, systems, competencies, and organisational structures that enable manufacturing companies to adapt quickly to seize opportunities, taking advantage of changes in market conditions, customer preferences, innovations, etc
- **The role of humans in production systems:** Employment in future production means advanced, professional, knowledge-based work where communication and co-operation between people and production systems are crucial
- **Digital and knowledge-based production:** New technology must enable efficient transformation of data into useable knowledge. A constant access to enormous amounts of information demands new methods to process and transform data
- **Production of innovative products:** Radically new product concepts that will require completely new production processes and materials for production to take advantage

of the potential in new materials, compounds, mechatronics, and micro- and nano-technology
- **Parallel product realisation:** Concurrency throughout the product realisation process with a focus on minimising the time from idea to delivering the eventual product to the customer

4.3 Manufacturing capabilities: enabling and success factors

Several international studies of the future of manufacturing identify a set of capabilities – associated with manufacturing firms and the national manufacturing 'ecosystem' more generally – which are necessary to meet the challenges (and opportunities) arising from the trends and drivers discussed above.

The recently published report by the US Institute for Defense Analysis paid particular attention to 'enabling factors' that influence the success in creating competitive manufacturing products, processes, and enterprises [IDA, 2012]. This included analysis of factors influencing where manufacturing firms choose to locate production-related activities; the manufacturing investments of key manufacturing economies; and the policies directly addressing manufacturing competitiveness being implemented by competitor economies [IDA, 2012]:

'Key framework conditions that set the stage for advances in manufacturing include government investments, availability of a high-performance workforce, IP regimes, cultural factors, and regulations. Also critical to manufacturing are capital, especially early stage VC; a workforce knowledgeable in science, technology, engineering, and mathematics disciplines; immigration policies; and industry standards. Demographics play a role: emerging economies tend to have younger populations. More advanced economies are ageing rapidly. These factors are relevant in a globalised marketplace, where national policies drive firm-level decision-making around investment levels in R&D, training, and location of research and manufacturing facilities'.

As discussed in Section 1.1, capabilities associated with the 'industrial commons'[3] are influencing policies and analyses related to the future of manufacturing. In particular, there is growing awareness of the need to nurture an 'ecosystem' of manufacturing-related know-how, competencies and capabilities, including: manufacturing engineering R&D; systems integration engineering; advanced materials processing; measurement and testing; standards and regulation; prototyping and test bed engineering; scale-up processes and engineering; etc [Pisano, 2009; Tassey, 2010; Grove, 2010].
Similarly 'common infrastructure of manufacturing technologies' has been identified within the Japanese 4th Basic S&T Plan as an important issue for the future of Japan's (production-based) industrial competitiveness [METI, 2010]. In particular the Plan identifies such infrastructure as necessary to respond to various future market needs and outlines the intention to promote "*R&D into the advancement of measurement / analysis*

[3] Gary Pisano and Wily Shih [Pisano, 2009] coined the term 'industrial commons' to refer to the shared industrial engineering know-how, facilities and capabilities in a manufacturing-based industrial cluster. They argue that, by analogy with common pasture in medieval villages where residents grazed their livestock together, the 'industrial commons' provides clusters of manufacturing-related firms (in particular SMEs) with an opportunity to draw upon a set of clustered capabilities and know-how: materials, machine tools, production technologies, fabrication facilities, technical standards, measurement, testing, etc, thus enhancing innovation capabilities.

techniques, high precision processing technologies, and built-in system development techniques, integration of elemental technologies, establishment of performance / safety assessment methods, and hardware (materials, components, and units) coordination with software" [CSTP, 2010].

As discussed in Section 2.3.4, the research agenda of the high profile Cluster of Excellence for '*Integrative Production Technologies for High Wage Countries*' at RWTH Aachen is structured around four 'integrative production' capabilities with potential to underpin manufacturing competitiveness in high wage economies [Klocke, 2009]. These are used to structure the 'roadmapping of production technologies for high wage countries' analysis of Schuh et al [Schuch, 2011].

4.4 Manufacturing and value creation

Many of the most recent national analyses of the future of manufacturing have given especially careful attention to the complex challenge of identifying those elements (and associated configurations) of modern manufacturing systems with the potential to capture significant value for the nation.

4.4.1 Economic value capture

In high wage economies, considerable effort is being directed to understanding how to achieve greater variability of products while at the same time being able to manufacture them at cost levels equivalent to mass production – i.e. value-optimised supply chains matched to particular products, without excessive planning overheads that compromise cost-effectiveness [Brecher, 2012; Klocke, 2009; ACATECH, 2010].

This is a central theme within the high profile 'Production in the Innovation Economy' initiative of the Massachusetts Institute of Technology which sets out to challenge "*the commonly held notion that simply investing in upstream innovation and R&D will automatically lead to prosperity that benefits the nation as a whole. Prosperity only emerges when innovations are translated to a stream of new products and services, which are then scaled-up in a way that creates jobs and opportunities for the whole population*" [MIT, 2011].

4.4.2 Manufacturing and social value creation

In some countries, national S&T policies, strategies and related foresight exercises are increasingly focused on social and socio-economic challenges. In this context, the future of manufacturing is explored in terms of its contributions to addressing such challenges, often with a particular emphasis on value creation (and value capture) within the national economy.

For example, in Japan the recent 4th Basic S&T Plan places particular emphasis on addressing "demand pull" social and economic challenges, in particular the promotion of *'green innovation'* (addressing environmental and resource efficiency challenges) and *'life innovation'* (advancing medicine and healthcare), with a view to enhancing industrial competitiveness and the wellbeing of Japan's citizens.

Similarly, in Germany, an important part of the policy discourse related to manufacturing is the role of production technologies in addressing important societal challenges, such as health, mobility, sustainability, etc as well as their associated value creation opportunities as 'new markets of tomorrow'. In the German '*High Tech Strategy*', manufacturing-related technologies are often given comparable status to novel emerging technologies (e.g. bio-, nano- or information & communications technologies) [BMBF, 2009] in terms of technological solutions to address socio-economic challenges. A recent study commissioned by the Federation of German Industries [BDI, 2012], explored future economic and social value creation across five multi-sector domains associated with socio-economic challenges and new markets: '*mobility*', '*climate & energy*', '*health & nutrition*', '*communications*' and '*security*'. While 'manufacturing' is not the key focus of the study there is an emphasis on industrial value creation.

4.4.3 Manufacturing and future value from technological innovation

An emerging emphasis in national studies analysing the future of manufacturing is the interdependence between production activities and technological innovation. There is growing awareness that a knowledge economy which loses interaction with its production base may lose the ability to innovate next generation technologies and products. Influential commentators have pointed to the fact that the off-shoring of production operations is all too often followed by a deterioration in other parts of the industrial system (e.g. reduced operations by local suppliers of materials, components, and production technologies; a decline in process engineering skills, manufacturing know-how and leadership; a deterioration of prototyping, test-bed and pilot-manufacturing infrastructure). This damage to the so-called "industrial commons" has the potential to reduce critical interactions between product development, next generation production technologies, and process engineering which can be a vital source of innovation. Furthermore, because emerging technologies often rely on elements of the "industrial commons" of more mature sectors, this process risks reducing a nation's capacity to compete in some of the most important new industries of the future. [Tassey, 2010; Berger, 2011; PCAST, 2011; Pisano, 2009; Grove, 2010; EOP, 2012].

4.5 Strategic priorities

As discussed above, manufacturing foresight exercises typically follow a sequence of analysis which explores: (1) trends influencing the nature of manufacturing; (2) the consequences of those trends, in terms of challenges to the competitiveness of national manufacturing systems; (3) capabilities necessary to meet those challenges –with particular attention to (4) opportunities for value creation (and capture).

The particular outputs of individual foresight exercises will vary depending on the missions and objectives of the lead stakeholders, but two broad categories of strategic priority themes that are often addressed are:

- R&D priorities to address innovation needs of future manufacturing systems
- Policy priorities associated with the framework conditions necessary to support the competitiveness of national manufacturing systems

4.5.1 Strategic priorities: research & innovation

The full set of research topics and challenges prioritised by different countries (through the processes outlined above) vary in emphasis, investment and specificity. Variations often reflect national science & technology strengths or the interests of dominant manufacturing industries within the economy. There is, however, significant consensus around a number of research challenges and topics. Some common manufacturing research priorities or “hot topic” themes that appear across all the leading manufacturing economies include, for example:

- Sustainable, resource-efficient manufacturing
- Production technology to exploit the potential of emerging technologies (in particular novel bio- and nano-technologies)
- Leveraging simulation and modelling techniques to address manufacturing challenges
- Flexible, rapidly responsive production systems for customised manufacturing

Some variations in themes and/or emphases between different nations include, for example:

- US emphasis on next generation materials (and novel materials engineering) for manufacturing
- Japanese focus on the implications of demographic changes: The prioritization of research on new production technologies for an ageing workforce; and opportunities associated with the manufacture of new products for an ageing population
- German efforts related to manufacturing processes that protect products from piracy
- Prioritization in Japan of visualization technologies and integration of IT systems with production technologies to enhance the competitiveness of manufacturing systems

Examples of manufacturing research & innovation priorities from recent foresight-related exercises in important manufacturing economies are summarised below.

4.5.1.1 Germany

Manufacturing research priorities identified in the *Production Research 2020* analysis, as well as ongoing important research themes identified in earlier foresight exercises and in interviews with manufacturing research leaders for this study include:

- **Energy, environmental and sustainability manufacturing challenges** including: production technologies for future energy systems and low carbon technologies (including standards development); resource-efficient manufacturing; value chains, production systems and processes for low carbon vehicles;
- **Market orientation and strategic product planning** including: software and product development, refinement of market and product planning tools;
- **Digital manufacturing & advanced automation** including: IT in the factory of tomorrow, simulation and modelling of products, production processes & manufacturing systems; robotics for services & logistics; human-machine interface;
- **Production systems & processes for emerging technologies** (and non-traditional “manufacturing” sectors) including: production processes and equipment for advanced materials, biotech and nanotechnologies, pharmaceutical factories and micro-level processing;
- **People in flexible & responsive manufacturing firms** including: the demographically-balanced factory, adaptation of working methods for older demographics;
- **Flexible production networks and systems for customised production** including the efficient development of innovative products; integration of novel materials,

production technologies and product development methods; flexible organization structures / supply chain management; and,
- **Protection of production know-how and products in global manufacturing systems** including: research addressing product piracy; production technologies for marking & registration, etc

4.5.1.2 China

The Chinese Medium- and Long-term National Plan for Science and Technology Development: 2006-2020 (the 'MLP') focuses on research activities designed to upgrade manufacturing industries using high technologies [USCC, 2011]. The MLP outlines ten prioritised fields, including ‘manufacturing technologies’ which includes the following research priority topics [MLP, 2006]:

- Basic and generic parts and components
- Digital and intelligent design and manufacturing
- Green technologies and equipment for processing industries
- Recycling iron and steel processing techniques and equipment
- Large-scale marine engineering technologies and equipment
- Basic raw materials (processing and extraction)
- Next-generation information functional materials and components
- Key accessory materials and engineering processes for the defense industry.

The MLP identifies a further eight ‘frontier technologies’ for priority funding, including ‘advanced manufacturing technologies’, which include: Extreme manufacturing technology; Intelligent service robots; service life prediction technologies. Other MLP prioritised fields, frontier technologies and research topics also involve manufacturing-relevant research, e.g.: new-generation Industrial biotechnology; advanced materials technology (breakthroughs in material design, assessing, and characterising, and in advanced manufacturing and processing technologies).

In 2009 the Chinese Academy of Sciences published a 2050 roadmap for Chinese S&T development to provide additional guidance beyond the MLP. The CAS report identifies 22 strategic technology issues that are perceived to be critical to China's future innovation needs, including manufacturing-related topics such as: “green manufacture of high quality elementary raw materials”, synthetic biology, and nanotechnology. The CAS roadmapping process also generated an ‘Advanced Manufacturing Technology’ roadmap with further analysis and recommendations.

4.5.1.3 Sweden

The ‘Swedish Production 2020’ study, discussed in Section 4.2, identified the following priority & emerging manufacturing research themes include:

- **Production systems**, including topics such as: adaptive production systems; virtual factories; the role of people in modern production systems; production logistics and enterprise networks
- **Integrated production & product development**, including topics such as: production requirements in early stages of product development, methods for virtual production & product development, analysis and optimisation of production & product development

- **Manufacturing processes**, including topics such as: processing of novel materials; virtual development methods for material processing and forming; production technologies for micro- and nano-structures; management of measurement data; and the characterisation of materials (from a production process perspective)

4.5.1.4 United States

The recent US National Strategic Plan for Advanced Manufacturing [EOP, 2012] highlights priority areas for federal investment in advanced manufacturing R&D, with particular emphasis on critical capabilities which the private sector is unlikely to invest in, notably emerging technologies with potential for broad adoption and commercialization or of critical national security importance. These investments are grouped into the following categories:

- Advanced Materials
- Production Technology Platforms
- Advanced Manufacturing Processes
- Data and Design Infrastructure

Further insight into US manufacturing research priorities can be gleaned from the range of recent workshops and symposia addressing the future competitiveness of US manufacturing. For example, the Interagency Workshop: '*Extreme Manufacturing – What are the technology needs for long-term US Manufacturing Competitiveness?'* reflects some of the key manufacturing research-related questions and priorities of US R&D mission agencies. The workshop was run by NIST in partnership with DARPA, NSF and NASA. A key aim of the workshop was to identify crosscutting and enabling R&D investments needed by the federal government to build the innovation infrastructure for successful US manufacturing enterprises. The topics identified for discussion were:

- **Future intelligent manufacturing systems:** Extremely agile, adaptive, and responsive manufacturing; rapid product realization: scale up of new emerging technology-based products; system modeling and simulation 'building blocks'; and highly integrated control of complex, precise processes throughout distributed multi level production
- **Extremely efficient and effective manufacturing**: Exceptionally competitive and affordable customised production; 3D printing; extreme improvements in usability of advanced technology for SME manufacturers; designed-in sustainability for value-based enterprises; and the "condominium" approach for dynamic, modular, affordable facilities infrastructure
- **Frontiers of manufacturing science:** Advanced bioscience and biosystems for manufacturing; computational biology for process control; precise, high volume directed self-assembly of multi-functional nano-microsystems
- **The Future Manufacturing Enterprise:** Dynamic collaboration across extremely complex multi-level, reconfigurable supply chains; rapid engineering and production of integrated high-confidence cyber-physical products and systems; tightly integrated design, test and validation across vastly distributed production environments; digital direct manufacturing of complex products and assemblies; service-oriented manufacturing; cloud manufacturing.

4.5.2 Strategic priorities: policy themes

Although many international manufacturing foresight studies carried out in recent years paid special attention to identifying research and innovation priorities to address the challenges facing their national manufacturing base, some exercises also identified priority policy-related themes.

Some common themes that emerged in several high profile analyses, include:

- Public-Private Partnerships to address future manufacturing challenges
- Manufacturing SMEs of the future
- Standards for next generation production technologies and manufacturing systems
- Future challenges for regional manufacturing clusters
- Manufacturing workforce of the future

4.5.2.1 Public Private Partnerships (PPPs)

A number of studies have suggested that the next generation of advanced manufacturing and processing technologies will be expensive to produce, and no one entity has all the expertise needed. Cooperative R&D is necessary to share costs, risks, and expertise. Equally, it has been recognised that where new infrastructure is required PPPs may be able to provide a solution.

> *'[Public Private Partnerships can] generate scientific and technical knowledge that is shared among many partners that leads to greater know-how, expertise and new capabilities that further innovative activity … [facilitating] technology transfer from invention to innovation.'*
>
> White Papers on Advanced Manufacturing [STPI, 2010]

This idea has received particular attention in the United States where a recent report by the President's Council of Advisors on Science & Technology [PCAST 2011]. This report highlighted the difficulties facing individual firms in making those investments required to fully develop many of the most promising emerging technologies or to create the full production infrastructure necessary to support high value manufacturing. The report points to opportunities where there is potential to appropriately complement private sector investment with public funds.

Key identified opportunities with the potential to overcome market failures include: investing in the advancement of new technologies with transformative potential; supporting shared infrastructure; and accelerating the manufacturing process through targeted support for new methods and approaches. PCAST recommend that the Government should co-invest in public-private partnerships to facilitate development of broadly-applicable technologies with transformative potential. Opportunities for investment should be selected based on a number of criteria, including where:

- Technology has a high potential payoff in employment and output
- Prospect of sustainable competitive advantage for the US
- Identifiable market failures which impede private investment
- Industrial partners are willing to co-invest and can invest at scale
- Investment will help anchor subsequent manufacturing in the US
- Shared infrastructure will help existing firms and industries compete globally.

A recent European Commission study on '*Key Enabling Technologies*' [EU 2010] also views investment in PPPs as a potential solution to the challenges facing advanced manufacturing in terms of the rising price of R&D, increased competition and short product lifecycles. This report recognises that it is often not possible for individual firms to meet the amount of costs required to develop leading-edge technologies.

A prominent EU example of a manufacturing-related PPP is the 'Factories of the Future' initiative, one of three PPPs as part of the European Economic Recovery Plan 2010-2013. This consists of a research programme of €1.2 billion to support the manufacturing industry in the development of new and sustainable technologies. The purpose is to help EU manufacturing, in particular SMEs, to adapt to global competitive pressures by improving the technological basis of manufacturing.[4]

The recent report from the World Economic Forum [WEF, 2012] also noted the need for Governments to invest in PPPs to provide necessary infrastructure support. The report argues that reinvestment in maintaining competitive infrastructure will become more critical for developed nations to keep pace with the newly developing nations. While infrastructure alone does not guarantee highly competitive manufacturing, a lack of infrastructure or a steadily declining infrastructure would have a negative impact on manufacturing competitiveness and create obstacles for the supply chain networks of global businesses.

4.5.2.2 The Manufacturing SMEs of the future

Most of the international studies of the future of manufacturing reviewed in this report paid particular attention to the consequences of 'mega-trends' and drivers for the competitiveness of manufacturing-related SMEs.

> *'SMEs are important actors in technology development. However, unpredictable and costly regulations sometimes hamper their innovation potential. … Awareness increasing and support for SMEs (simplification, better regulation, technology-transfer etc) can help reduce these costs and remove obstacles to cross-border innovation.*
>
> Key Enabling Technologies [EU, 2010]

This is taken particularly seriously in Germany where, for example, the BMBF analyses for "Research for Tomorrow's Production" (and subsequent funding programmes) are strongly focused on providing research results for broad use by German SMEs [BMBF, 2010; Abele, 2010].

In the US, the recent report of the President's Council of Advisors on Science & Technology [PCAST, 2011] highlights potential of shared facilities and infrastructure to ensure the future competitiveness of small and medium-sized manufacturing-based firms.

The EU study on '*Key Enabling Technologies*' [EU 2010] acknowledged that SMEs are important for technology development but noted that unpredictable and costly regulations could hamper their innovation potential. Access to capital tends to be a bigger constraint for SMEs and SMEs may not have the capability to reach potential innovation partners in other countries and miss out on important business opportunities. As a consequence, a number of recommendations focused on reducing costs and removing obstacles for SMEs.

[4] For further details see http://ec.europa.eu/research/industrial_technologies/factories-of-the-future_en.html

In Japan, the most recent set of Manufacturing 'Monozukuri' White Papers exploring the future challenges to Japanese manufacturing pay careful attention to the competitiveness challenges facing SMEs. In particular, a consistent distinction is made between issues facing SMEs and other firms, in key areas such as: human resources needs, value of the yen, R&D priorities, R&D taxation, and support for overseas business expansion.

> *'In various regions of the U.S. entrepreneurs are collaborating with local researchers, educators and industry leaders to foster specialized knowledge, technical expertise and cutting-edge products. These efforts will help American businesses retain and achieve new levels of competitiveness.'*
>
> Framework for Revitalizing American Manufacturing [2009]

The Swedish Production 2020 analysis highlights the importance of SMEs in the Swedish industry structure. Reflecting some of Sweden's key sectoral strengths (in automotive and telecommunications), Swedish manufacturing industries are often made up of long value chains, where bigger firms work together with a large number of much smaller supplier companies. This manufacturing system configuration means greater importance is placed on rapid information processing and efficient supply chain logistics. Supporting and developing SME capabilities within such value chains is considered a particularly important challenge for the future of Swedish manufacturing competitiveness and a priority theme for Swedish manufacturing-related research.

> *'While [manufacturing R&D projects] stimulate innovations, they have to be supported by a suitable tool ensuring the efficient diffusion of these innovations into the market. Standardisation can serve as such a tool.'*
>
> *Manufacturing Vision 2020,* Intelligent Manufacturing Systems

4.5.2.3 Standardization and the future of manufacturing

Several international studies have identified the potentially important role of standardization in supporting the emerging manufacturing-related technologies and systems of the future.

In particular, they point to the potential for standards to help the diffusion of new types of manufactured products, production technologies or systems into practice [IMS, 2010; Jovane, 2007]. Some analyses and strategies related to the future of manufacturing highlight the strategic importance of enhancing the presence and influence of national manufacturing systems within international standards-setting structures, for example:

In Japan, the role of standardization is highlighted in the Ministry of Economics, Trade & Industry's 'Monozukuri' White Papers in the context of addressing challenges to future manufacturing competitiveness. Particular attention is paid to a perceived lack of awareness by many Japanese manufacturing firms of the importance of international standardization. This issue is highlighted, more generally, in the Japanese 4th Basic S&T Plan in the context of maintaining competitiveness in the face of increasing 'open innovation' and R&D globalization.

In the United States, the role of standards in supporting the future competitiveness of US manufacturing firms is highlighted within the recent *National Strategic Plan for Advanced Manufacturing*. For example, the Strategy points to the role of standards (in particular those related to system interfaces, measurement and test methods, and process control systems) in allowing firms within supply chains to align their product and process capabilities with new value capture opportunities. The Strategy points to the potential of public-private partnerships (as discussed above) to facilitate participation in standard-setting, accelerating standards adoption.

4.5.2.4 Future challenges for regional manufacturing clusters

A number of international manufacturing foresight-related studies address the implications of megatrends and drivers at the level of regional manufacturing clusters.

In the US, in the President's Budget FY2010 proposed $50million spending in regional planning to support the creation of regional innovation clusters that leverage existing business strengths to boost job creation and economic growth in both rural and metropolitan areas. Initial meetings of the US Advanced Manufacturing Program have been hosted on a regional basis reflecting strong geographical variations in manufacturing sectors, activities and strengths. There have also been a number of State-level studies, e.g. the recent manufacturing roadmap of the Government of Massachusetts '*Building Bridges to Growth'* [MTPC, 2011]. And, as discussed elsewhere in this report, the US policy discourse on future of manufacturing emphasises the importance of regional 'industrial commons' of manufacturing know-how, capabilities and infrastructure.

This regional dimension also features in a range of other analyses, for example: the report by the EU Commission's High Level Working Group on Advanced Manufacturing Systems [EU, 2010] points to the need for policies to address regional cluster development; and the Japanese Ministry of Economics, Trade & Industry's Manufacturing 'Monozukuri' White Papers [METI 2011] also explore the importance of regional R&D and infrastructure support for strengthening of industrial capabilities.

4.5.2.5 The manufacturing workforce of the future

> '*Today's skills gap will not close in the near future. Companies and countries that can attract, develop and retain the highest skilled talent – from scientists, researchers and engineers to technicians and skilled production workers – will come out on top*'
>
> World Economic Forum [WEF, 2010]

The changing needs of national manufacturing workforces are an important theme in almost all 'future of manufacturing' analyses explored in this study, and in particular in high wage manufacturing economies. The focus in studies has not solely concentrated on the level and type of skills required of the workforce in the future but has also considered implications for retaining employment in manufacturing across all skill levels.

In Germany, the future manufacturing workforce (including skills, people-oriented production technologies, and demographics) has been an important part of the 'Framework Concept' [BMBF, 2007] for analysing future manufacturing needs for many years; and continues to be an important part of the ongoing debate on capturing value from manufacturing in a high wage economy. A recent workshop hosted by the German National Academy of Science & Engineering considered a number of issues relating to human capital [Acatech, 2010]. The report noted that the labour market is becoming both increasingly complex and dynamic where, because of globalisation of education and training, knowledge and mobility, there is a marked drop in the length of time an employee stays in a company. Mobility of employees is low cost but that brings with it both advantages and disadvantages. There was a recognition that skilled elites are essential for the continued existence and competitiveness of Germany as a production location and that more needed to be done to support their continued training and development to encourage them to stay in the country. Demographics also mean that German companies face the problem of an ageing workforce and consequent loss of employee knowledge and skills.

The future manufacturing workforce is also an important theme within Japanese analysis of the future competitiveness of ‘monozukuri’ [METI, 2011] with particular attention paid to the roles of engineering universities, colleges of technology, specialised community and training colleges.

The PCAST [2011] report to the US President drew attention to the workforce in a number of ways. The report concluded that ‘advanced manufacturing’ has the potential to create and retain high-quality jobs in the US. However, they found that the US lagged behind competitor nations in providing the skilled workforce needed for advanced manufacturing and recommended that the government should ensure a supply of skilled workers, through policies that cultivate and attract high-skilled talent. PCAST also recommended that the Federal Government should:

- Strengthen science, technology and mathematics (STEM) education; and,
- Expand the number of high-skilled foreign workers that may be employed by US companies.

The recent US National Strategic Plan for Advanced Manufacturing has since announced as one of its key objectives the expansion of the number of workers with the skills required by future advanced manufacturing sectors with an education and training system more responsive to the demand for manufacturing related skills.

5. Concluding observations & recommendations

This study reviewed international analyses of the 'future of manufacturing' carried out in important manufacturing economies. This review was designed to support the work of the UK Government Office for Science Manufacturing Foresight team and Lead Expert Group by identifying potentially useful manufacturing foresight practices, dimensions of analysis, and thematic focus areas; as well as providing insights into the manufacturing priorities, policies and strategies of competitor economies.

The relatively sparse and diverse nature of the foresight studies identified in the course of this review means it is challenging to draw specific conclusions about their relative effectiveness, quality and findings. Consequently, the following concluding observations focus on identifying promising practical approaches and dimensions of analysis for exploring the 'future of manufacturing' with the potential to be effectively adapted or adopted to a UK context.

1. An 'ecosystem' view of manufacturing: Where practical and appropriate, projects should endeavour to account for complex interdependencies across a range of sectors that contribute a variety of components, materials, production systems and subsystems, producer services and product-related service systems.

2. Adopting a conceptual framework that allows for a broad and inclusive definition of 'manufacturing': There may be advantages in a definitional framework that involves one or more of the following elements: Processes and technologies (new ways of accomplishing the "how to" of production); smart manufacturing systems and enterprise concepts; advances in science and engineering research (breakthroughs with the potential to be drivers for advanced manufacturing); advanced products (typically technologically complex products, new materials, products with highly sophisticated designs).

3. Distinguishing between different types of manufacturing firms: Care should be taken to distinguish between different categories of firm – for example, between factory equipment makers (producers of capital goods) and factory users (producers of consumer goods); between small and medium-sized enterprises and multinational firms; between firms operating at different stages of the industrial value chain. Different firms will face different challenges to their future competitiveness, have different perspectives and levels of awareness of manufacturing trends and drivers, and have different potential contributions to manufacturing 'ecosystems' and economic value capture.

4. The interdependence between manufacturing and innovation: It may be worth exploring the quality of linkages between the UK research base and manufacturing activities, for example: the role of UK technology innovation centres, such as Technology Strategy Board 'Catapults', in maintaining these linkages and the ability to address manufacturability challenges of emerging technologies.

5. High priority emerging technologies and future research domains: There are a number of promising emerging technologies and future research fields which receive considerable attention in international foresight studies because of their disruptive potential for the future of manufacturing (e.g. additive manufacturing; sustainable manufacturing**;** simulation & modelling; etc). There may be merit in exploring the potential impact of selected technologies on the future of UK manufacturing.

6. Public Private Partnerships (PPPs): One feature of international studies that may be worth considering in a UK context is consideration of the potential of public private partnerships to address manufacturing innovation challenges – i.e. pre-competitive consortia which can facilitate the development of technology platforms, potential; shared infrastructure, and design methodologies with the potential to transform future manufacturing.

7. The role of technical standards in supporting future manufacturing competitiveness: A number of international studies point to the potentially important role of standards in supporting the emerging manufacturing-related technologies and systems of the future. In particular, they point to the potential for standards to help the diffusion of new types of manufactured products, production technologies or systems into practice. This theme may be worth exploring in the context of the current 'Future of Manufacturing' foresight exercise.

8. Engaging with established manufacturing community events: One potentially noteworthy practice, observed in a number of international manufacturing foresight initiatives, involved manufacturing foresight teams systematically engaging with established fora or conferences of different manufacturing stakeholder groups in order to gather insights from those communities. In particular, there are opportunities to have collective discussions with a broad range of community representatives.

9. Leveraging science & technology foresight studies and sector roadmaps: Although beyond the scope of this review, there is - in principle – potential merit in scanning existing science-, technology-, and sector-specific foresight exercises for trends and insights related to the future of manufacturing itself. In this context, there may be potential for the current 'Future of Manufacturing' foresight study to identify particular manufacturing-related questions which could be systematically incorporated into future science-, technology-, and sector-foresight studies to support ongoing manufacturing-related policy development.

10. The role of manufacturing in addressing future societal challenges: A number of international foresight-related analyses address the potential role of manufacturing to capturing socio-economic value, in particular the contribution of production (and emerging production technologies) to tackling a range of social 'grand challenges'. There may be merit in exploring the potential role of UK manufacturing capabilities in addressing key societal challenges associated with, for example, healthcare, mobility, climate change and sustainability.

References

Abele, E., Reinhart, G., 2011. Zukunft der Produktion: Herausforderungen, Forschungsfelder [The Future of Production: Challenges, Research Areas, Opportunities], Hanser Fachbuchverlag

Abele, E., 2010. Herausforderungen für die Produktion(sforschung) 2020 [Challenges for Future Production (Research)], Karlsruhe Production Research Congress 2010.

ACATECH, 2010. Product Development: Value-added and Employment in Germany. Report of a workshop (Production Technology Centre, Leibniz University of Hanover) for the ACATECH 'Product Development' Thematic Network project on 'Sustainable value added [production] networks for tomorrow's markets'. German National Academy of Science & Engineering

AMP, 2012. Advanced Manufacturing Partnership. Department of Energy website: http://www1.eere.energy.gov/manufacturing/amp/

BDI, 2011. Germany in 2030: Future Perspectives for Value-Creation. A report by Z_punkt for the Federation of German Industry.

Berger, S. (2011). Why Manufacturing Matters, Technology Review.

Bessey, E., Bueno,R., Decubber, C. , Chlebus, E., Goericke, D., Groothedde, R. Hanisch, Ch., Jovane, F., Mendonca, J., Paci, A., Westkämper, E., Williams, D. (2007). Research, Technology and Development for Manufacturing. In Jovane, F., Westkaemper, E.. The ManuFuture Road, pp. 119. Springer.

BMBF, 2006. The High Tech Strategy for Germany. Federal Ministry for Education & Research (BMBF).

BMBF, 2007, Untersuchung zur Actualisierung de Forschungsfelder für das Rahmenkonzept „Forschung für die Produktion von morgen“ [Framework Concept for Tomorrow's Production]. Final Report, February 2007. Federal Ministry for Education & Research (BMBF). BMBF, 2009, Research & Innovation for Germany: Results & Outlook

Brandes, F., 2008. 'The Future of Manufacturing in Europe: A Survey of the Literature and a Modelling Approach'. Foresight Brief 137, European Foresight Monitoring Network

Brecher, C. (Ed.), 2012. Integrative Production Technologies for High Wage Countries. Springer

Corwin, J., Puckett, R., 2009. Japan's Manufacturing Competitiveness Strategy: Challenges for Japan, Opportunities for the United States. A Report to the US Department of Commerce, International Trade Administration.

CSTP, 2010. Japan's Science and Technology Basic Policy Report, Japanese Council for Science and Technology Policy

Cuhls, K., (2009). The German BMBF Foresight Process, European Foresight Platform, Brief No. 174, EU Commission DG Research

Cuhls, K., Beyer-Kutzner, A., Ganz, W., Warnke, P. (2009). The methodology combination of a national foresight process in Germany. Technological Forecasting & Social Change 76, pp. 1187–1197

Dugan, R.E., 2010. Defense Advanced Research Projects Agency: Statement by the Director to US House of Representatives, Testimony to Congress

EOP, 2009. A Framework for Revitalizing American Manufacturing, Executive Office of the President, December 2009

EOP, 2012. A National Strategic Plan for Advanced Manufacturing. Executive Office of the President and National Science & Technology Council. White House website.

EU, 2010. High Level Group on Key Enabling Technologies. Thematic Report by the Working Team on Advanced Manufacturing Systems

FhG ISI, 2010, New Future Fields, A Foresight Process Study for the German Federal Ministry of Education and Research (BMBF)

Fraunhofer, 2011. Fraunhofer Group for Production, Fraunhofer-Gesellschaft website: http://www.fraunhofer.de/en/institutes-research-establishments/groups-alliances/production.jsp

Fujimoto, T., 2011. The Japanese Manufacturing Industries: Its Capabilities and Challenges. Presentation to the 21st International Conference on Flexible Automation and Intelligent Manufacturing.

FutMan, 2003. The Future of Manufacturing in Europe 2015-2020: The Challenge for Sustainability. Project report to the European Commission

GO Science, 2010. Technology and Innovation Futures: UK Growth Opportunities for the 2020s. Foresight Horizon Scanning Centre, Government Office for Science

Grove, A., 2010. How America can create jobs. Businessweek, Bloomberg Businessweek, July, 2010

GSaME, 2010. Graduate School for Advanced Manufacturing Engineering website: http://www.gsame.uni-stuttgart.de/EN [Last accessed, November 2010]

Hu, S.J., Chaffin, D., Koren, Y., 2010. Reshaping US Manufacturing for Global Competiveness, S. Jack Hu, Don Chaffin, Yoram Koren, Workshop report submitted to the National Science Foundation

IDA, 2012, Emerging Global Trends in Advanced Manufacturing' by the Institute for Defense Analysis

IMS, 2010. IMS2020 Roadmap: Roadmap on Sustainable Manufacturing, Energy Efficient Manufacturing and Key Technologies, Intelligent Manufacturing Systems

IMS, 2011. World Manufacturing Forum website:

IMTI, 2003. 21st Century Manufacturing Taxonomy: A Framework for Manufacturing Technology Knowledge Management, IMTI, Inc.

IVA, 2006. Production for Competitiveness: Swedish production potential, A Project Report by the Royal Swedish Academy of Engineering Sciences

Jovane, F., Westkaemper, E. (2007). The ManuFuture Road, Section 2.2.5, pp. 15-16

Klocke, F., 2009. Production Technology in High-Wage Countries: From Ideas of Today to Products of Tomorrow. Industrial Engineering & Ergonomics, 1, pp. 13-30

LeJour, A., Veenendaal, P., Verweij, G., van Leeuwen, N. (2006). WorldScan: a Model for International Economic Policy Analysis. CPB Document 111, Netherlands Bureau for Economic Policy Analysis

Lejour, A., Verweij, G., 2008. Two quantitative scenarios for the future of manufacturing in Europe. A Report by CPB, Netherlands Bureau for Economic Policy Analysis

METI, 2010. The 4th Science and Technology Basic Plan of Japan. Ministry of Economics, Trade & Industry website: www.mext.go.jp/component/english/__icsFiles/afieldfile/2012/02/22/1316511_01.pdf

METI, 2011. White Paper on Monozukuri. Ministry of Economics, Trade & Industry website: http://www.meti.go.jp/english/report/data/Monodzukuri2011_02.pdf [updated January 4, 2012]

MIT, 2012. Production in the Innovation Economy program. Massachusetts Institute of Technology website: http://mit.edu/pie/

NAICS, 2007. North American Industry Classification System Definitions. US Department of Commerce.

NAE, 2012. Making Things: 21st Century Manufacturing & Design. Report of a Symposium of the National Academy of Engineering, National Academies Press

NAM, 2009. The Facts about Modern Manufacturing, The Manufacturing Institute, National Association of Manufacturers, 8th Edition

NDU, 2009. Manufacturing Industry. Final Report. Industrial College of the Armed Forces, National Defense University, Fort McNair.

NIST, 2010. Manufacturing and Biomanufacturing: Materials Advances and Critical Processes, Technology Innovation Program White Paper, National Institute of Standards & Technology

NIST, 2011. NIST Workshop: Extreme Manufacturing – What are the technology needs for long-term US Manufacturing Competitiveness?, National Institute of Standards & Technology website

NSTC, 2009. Manufacturing the Future: Federal Priorities for Manufacturing R&D. A report of the Interagency Working Group on Manufacturing R&D of the US National Science & Technology Council

O'Sullivan, E., 2011. International Approaches to Manufacturing Research. A Report to the Engineering & Physical Sciences Research Council. Institute for Manufacturing, University of Cambridge

PCAST, 2010. PCAST Launches Policy Forum on the Future of U.S. Advanced Manufacturing, Office of Science & Technology Policy, White House website.

PCAST, 2011. Report to the President on Ensuring American Leadership in Advanced Manufacturing. Office of Science & Technology Policy, White House website.

Pisano, G.P., Shih, W.C., 2009. Restoring American Competitiveness, Harvard Business Review

Popper, R., 2008. How are foresight methods selected? Foresight, 10(6), pp. 62-89

RWTH, 2010. Cluster of Excellence: Integrative Production Technology for High-Wage Countries. [English language brochure]. RWTH Aachen.

USMCI, 2012. Make: An American Manufacturing Movement, US Manufacturing Competitiveness Initiative, US National Competitiveness Council

ManuFuture, 2011. ManuFuture 2011 Conference. ManuFuture website:

Schuh, G., Aghassi,S., Orilski,S., Schubert, J., Bambach, M., Freudenberg, R., Hinke, C., Schiffer, M., (2011). Technology roadmapping for the production in high-wage countries, Production Engineering, 5(4), pp. 463-473

SRI, 2004. Advanced Technology & the Future of U.S. Manufacturing. A report by SRI for the Manufacturing Extension Partnership of the National Institute of Standards & Technology (NIST)

STPI, 2010. White Papers on Advanced Manufacturing Questions, Prepared for the Advanced Manufacturing Workshop of the President’s Council of Advisors on Science and Technology (USA), Science & Technology Policy Institute

Sturgeon, T.J. (2001) How Do We Define Value Chains and Production Networks?, IDS Bulletin, 32 (3), pp 9–18

Tassey, G., 2010. Rationales and mechanisms for revitalizing US manufacturing R&D strategies, J. Technol. Transf.

Teknikföretagen, 2009. Swedish Production Research 2020, A Report by the Association of Swedish Engineering Industries

USCC, 2011. China’s Program for Science and Technology Modernization: Implications for American Competitiveness. A report by CENTRA Technology for the U.S.-China Economic and Security Review Commission

Van der Zee, .F., Brandes, F. (2007). Manufacturing Futures of Europe: A Survey of the Literature. A Background Study by TNO for the European Commission's Future of Manufacturing in Europe Initiative

VINNOVA, 2010. Summary Impact analysis of Support for Strategic development areas in the Swedish Manufacturing Industry, Report by Technopolis for VINNOVA

Von Opstal, D. (2010). Commentary on Gregory Tassey’s ‘‘Rationales and mechanisms for revitalizing US manufacturing R&D strategies’’, J Technol Transf

WEF, 2012. Future of Manufacturing: World Economic Forum Global Workshops. World Economic Forum website

Westkaemper, E., 2010. The European perspective on Factories of the Future, presentation to the Productivity Forum 2010

Yoshikawa, H. (1995). Manufacturing and the 21st century: Intelligent manufacturing systems and the renaissance of the manufacturing industry. Technology Forecasting & Social Change

Appendix 1: Selected international future of manufacturing-related studies (including national strategies, workshop reports, etc)

Title	Country	Year	Study (Exercise details)	Lead Stakeholder (Organisation Type)	Time Horizon
Trends in Manufacturing to 2020	Australia	2011	Discussion paper collating views of stakeholders including: industry; the R&D community; innovation advisory bodies; unions; and, the public sector.	Industry Innovation Council established by the Australian Govt	2020
Manufacturing Futures: Achieving Global Fitness	Australia	2006	Survey of 800 Manufacturers plus: desk research; workshops with 200+ business leaders; and, in-depth interviews with 20 large manufacturers.	Australian Industry Group, (industry association)	not specified
Transition to Sustainable Production Systems: Austria 2020	Austria	2003-2005	Study of two sustainable industries. Engaged with stakeholders through workshops to develop scenarios.	Federal Ministry for Transport, Innovation and Technology	2020
Production Chains 2016 - The Brazilian Technology Foresight	Brazil	1999	Study of Production chains in 4 key industries. Variety of approaches including Delphi surveys, Scenario	Ministry of Development, Industry and	2016

Programme			analysis, stakeholder input, etc.	Trade	
The future of manufacturing in Canada: Perspectives and Recommendations on International Business Development	Canada	2005	Survey conducted in 2004, followed by extensive consultation with manufacturers (900+), and 36 community roundtables (public for a involving 2500+ from business, academia, local government etc)	Canadian Manufacturers and Exporters (industry association)	2020
China: Advanced Manufacturing Technology in China: A Roadmap to 2050	China	2011	Technology roadmap - research engaged with over 300 experts, included regular workshops, and peer review mechanism,.	Chinese Academy of Sciences (learned society)	2050
Technological Revolution and China's Future-Innovation 2050	China	2009	Foresight	Chinese Academy of Sciences (learned society)	2050
Medium- and Long-term Plan for Science and Technological Development 2006-2020	China	2006	Official Policy Document	The State Council of China	2020
Research 2015: A Basis for Prioritisation of Strategic Research	Denmark	2008	Catalogue of strategic research themes - based on mapping, analysis and dialogue - engaged with stakeholders from government, academia, industry, and general public.	Ministry of Science Technology & Innovation	2015
Manufacturing Visions (ManVis)	EU	2005	Delphi-survey in 22 countries (3,000 European manufacturing experts)+ workshops and interviews to collect	Fraunhofer ISI (public research institute) study	2020

			the "views of stakeholders and overseas experts"	for the European Commission	
Manufuture Workprogramme "New Production"	EU	2007	Roadmapping (participation of "key actors in each of 25 manufacturing sectors and the industrial automation industries", also using outcomes from other Roadmapping initiatives)	Fraunhofer IPA, Public Research Centre (study for EU Commission)	15
High level Group on Key Enabling Technology	EU	2010	High-level Group of 27 members. Conducted SWOT analysis re: Advanced Manufacturing Systems	European Commission	2020+
Produktionsforschung 2020 [Production Research 2020]	Germany	2010	Research Strategy / Expert Consultation. Led by academics involved research institutes, learned societies, industry associations, unions and other public stakeholders. Used combination of methods including expert groups, data mining and bibliometric analysis.	Federal Ministry of Education and Research	2020
New Future Fields	Germany	2009	Research strategy - included workshop and interviews with experts, on-line survey, environmental scanning, and analysis.	Fraunhofer ISI (public research institute) study for Federal Ministry of Education and Research	2020+
The National Manufacturing Strategy for India	India	2006	Expert report	National Manufacturing Competitiveness Council	2016

				(governmental council)	
Monozukuri White Papers	Japan	2011	Expert Report - Analysis and recommendations for future government policy on Manufacturing Industries	Ministry of Economics, Trade & Industry	mid- to long-term
Japanese 4th basic Science &Technology plan	Japan	2010	5-year national plan with a 10-year forward look. Plan advances 5 mid- to long-term objectives aimed at making Japan a country that achieves sustainable growth, high quality of life and takes the initiative in solving global issues.	Council for Science & Technology Policy	2015
Vision 2025 - Korea's Long Term Plan for Science and Technology Development	Korea	2000	Long-term blueprint for national scientific and technological development. Detailed action plan to be updated every 4-5 years.	Ministry of Science & Technology	2025
The Future Perspectives and Technology Foresight of Korea. Challenges and Opportunities.	Korea	2005	Conducted, 2003-2004, group of experts identified future prospects and needs, and then ran a survey of 1000 experts and 1000 members of the public, followed by an internet based Delphi survey, finally developed scenarios.	Ministry of Science & Technology	2015+
Production Research 2020: Strategic Research Agenda	Sweden	2008	Review of national and international studies + Surveys to manufacturing firms + Consultations to research institutes	Association of Swedish Engineering Industries (industry association)	2020

Technology and Innovation Futures: UK Growth Opportunities for the 2020s	UK	2010	Forward look at developments which have the potential to support sustained economic growth. Based on interviews and workshops with 180 representatives from industry, research, international institutions and social enterprises.	Foresight Horizon Scanning Centre, Government Office for Science	2020+
Visionary Manufacturing Challenges for 2020 (NRC, 1998)	USA	1998	Expert report - Committee of 13 individuals with expertise in manufacturing operations, management and practices; manufacturing technology education and training; social, behavioural and political science; and technology forecasting. The group included representatives from small, medium and large companies in a variety of industries. Gathered data through workshop and Delphi survey.	National Research Council	2020
Advanced Technology and the Future of U.S. Manufacturing (SRI, 2004)	USA	2004	Workshop report - interdisciplinary group of leading researchers challenged to discuss and debate long-run opportunities for US manufacturing and to consider the role of advanced technology and innovation	Stanford Research Institute (non-profit research institute) study for the National Institute of Standards & Technology	long-run
Manufacturing the Future (NSTC, 2008)	USA	2008	Research strategy - identifies and describes R&D priorities for the future of 3 critical, high-tech US	National Science & Technology Council	mid-long-term

			manufacturing areas		
White Papers on Advanced Manufacturing Questions for the President's Council of Advisers on Science and Technology	USA	2010	White Papers - prepared for the Advanced Manufacturing Workshop of the President's Council of Advisers on Science and Technology	Science and Technology Policy Institute (government-funded think-tank) report for the President's Council of Advisers on Science and Technology	mid-long-term
Extreme Manufacturing Workshop: Technology Needs for Long-Term US Manufacturing Competitiveness	USA	2011	A Public Workshop exploring the role of technology in America's manufacturing future. Workshop Report outlining findings and conclusions for future action.	National Institute of Science & Technology, in partnership with DARPA, NSF and NASA	Long-term
Report to the President on Ensuring American Leadership in Advanced Manufacturing	USA	2011	Expert report - provides a strategy and specific recommendations for revitalizing the US' leadership in advanced manufacturing. Evidence gathered from workshops and interviews with leading manufacturing executives, innovation experts, industry groups, government officials and academia.	President's Council of Advisors on Science and Technology	Mid-long-term

Make: An American Manufacturing Movement	USA	2011	Expert report - builds on earlier Global Manufacturing Competitiveness Index and a series of interviews with 400+ senior manufacturing executives worldwide plus a series of workshop events. Identifies 5 specific challenges and offers solutions.	US Council on Competitiveness	mid-long-term
Emerging Global Trends in Advance Manufacturing	USA	2012	Aimed to identify emerging global trends in advanced manufacturing and to propose scenarios for the future of advanced manufacturing	Institute for Defence Analysis (government think-tank) report for the Office of the Director of National Intelligence	10 and 20 years
Production in the Innovation Economy (MIT)	USA	2012 - ongoing	Commission from a range of academic disciplines aims to analyze the state of production in the United States and to propose new routes from innovation through manufacturing to jobs and growth in the United States.	Massachusetts Institute of Technology	mid-long-term
Building Bridges to Growth: A roadmap for Advance Manufacturing in Massachusetts	USA	2011	State focused study with an agenda to improve the competitiveness of Massachusetts Advanced manufacturing.	State Government of Massachusetts	mid-term
World Economic Forum Future of Manufacturing Project Description	WEF	2011	Project established as a result of high-level workshops calling for generation of strategic manufacturing insights and recommendations for senior executives and policy makers.	World Economic Forum (independent international organization)	5, 10 and 15 years

Appendix 2: Selected international workshops, symposia and summits (addressing 'future of manufacturing'-related themes)

Lead Stakeholder	Country	Year	Title	Event details
National Academy of Engineering	USA	2010	**Making Things:** **21st Century Manufacturing & Design**	• Insights from 7 highly influential thought-leaders from academia, business and government • Explored different aspects of manufacturing and opportunities for engineering community • Future of manufacturing in world of globalization, open innovation, biomanufacturing and next generation robots • Repeated themes, including: jobs, role of government, education & skills
National Institute of Standards & Technology (in partnership with DARPA, NSF and NASA)	USA	2011	**Extreme Manufacturing: What are the technology needs for long-term US Manufacturing Competitiveness?**	• Forum for interagency initiative discussions. • Aim to identify crosscutting and enabling federal R&D investments to build the innovation infrastructure for successful US manufacturing enterprises • Start development of a long-term vision of future manufacturing; including the technologies needed to reach this vision and roadblocks to future success
GATech (Oct., 2011)	USA	2011	**Advanced Manufacturing Partnership Regional Meetings**	• Hosted by leading US university members of AMP • Identify opportunities for emerging technologies with potential to transform U.S. manufacturing

MIT (Nov., 2011)				• Identify collaborative approaches to realise these opportunities • Explore key themes:' Technology development'; '*Education and workforce development'; 'Facility and infrastructure sharing'; 'Policies that could create a fertile innovation environment'*
Georgia Tech hosted SRI event for the Futures Group of the Manufacturing Extension Partnership, NIST	USA	2004	**Advanced Technology & the Future of U.S. Manufacturing**	• Aim to provide better understanding of major changes in nature of manufacturing driven by globalization, rise of BRIC economies, technological advances, etc. • An interdisciplinary group of leading researchers at GATech (from science and engineering, management, economic development, and public policy) • Looked beyond the short-term business cycle and immediate economic issues to explore longer-run opportunities
BMBF (Ministry of Education & Research)-funded Conference	Germany	2010	**10th Karlsruhe Production Research Congress**	• Over 600 participants from industry and academia (~50:50) • Discuss the latest results of research production • Conference theme "Production in Germany has a future" addressed the issues and challenges facing the manufacturing industry and production research in 2020. • Forums on: Products of tomorrow; Resource-efficient manufacturing; Innovative SMEs in a global manufacturing system; Trends for future product development; Production technologies and equipment of the future; Future manufacturing organizational and workforce challenges
German National Academy of Science &	Germany	2010	**Product Development: Value-added and Employment in**	• Part of the ACATECH 'Product Development' Thematic Network project on 'Sustainable value added [production] networks for tomorrow's markets'

Engineering Hosted by Production Technology Centre (PZH), Leibniz University of Hanover			**Germany**	• Key questions, included: *What does future hold for current manufacturing industry in Germany? Is there a way to reconcile higher economic value capture in [a high wage economy like] Germany and the needs of potential target markets? How a future blueprint might look like in the next 20 years for a vision and a model of industrial production in Germany? What is the role of politics, industry and science for implementing this blueprint for the future?*
Swedish Production Academy	Sweden	2007	**Swedish Production Symposium**	• Identified important emerging research domains and challenges relevant to the future of Swedish manufacturing competitiveness • Fed findings into "Swedish Production 2020" initiative • Collaboration between Teknikföretagen and Swerea IVF to present shared vision from industry and academia of what Swedish manufacturing industries would look like in 2020
Sponsored by the IMS network and the 7th Framework Programme of the EU Commission		2011	**World Manufacturing Forum**	• 320 representatives from industry, academia and government • Thematic sessions on issues such as: What skills and competencies will be needed for manufacturing in 2020? Are industrial policies keeping pace with global-manufacturing reality? Will economies become unstable by keeping their markets open? How to create better workplaces? • Endeavour to build consensus on a vision of global manufacturing challenges (and consequences for sustainability, growth models and policies • Endeavour to stimulate bottom-up ideas to promote international R&D and innovation partnerships

World Economic Forum		2011	**Future of Manufacturing: World Economic Forum Global Workshops**	• High level workshops in Tianjin, Davos, and Rio • Extended stakeholder dialogue • Involved Board-level / CEO champions • Goal to generate strategic manufacturing insights and recommendations for senior executives and policy-makers • Feed findings back to Future of Manufacturing task force. Platform for dialogues at selected regional Summits and 2012 Annual Meeting in Davos
ManuFuture, a European Commission initiative		2011	**ManuFuture 2011 Conference**	• Main objective: Vision of future manufacturing and its role in further growth of Europe - building smarter, greener and more competitive EU industry • Key topic areas: Current stage of research & innovation in advanced manufacturing; role of SMEs in transforming EU economies; industrial education; effective models of academia-research-industry cooperation; cooperation between old and new EU states

Foresight
1 Victoria Street
London SW1H 0ET
www.bis.gov.uk/foresight
URN 13/836