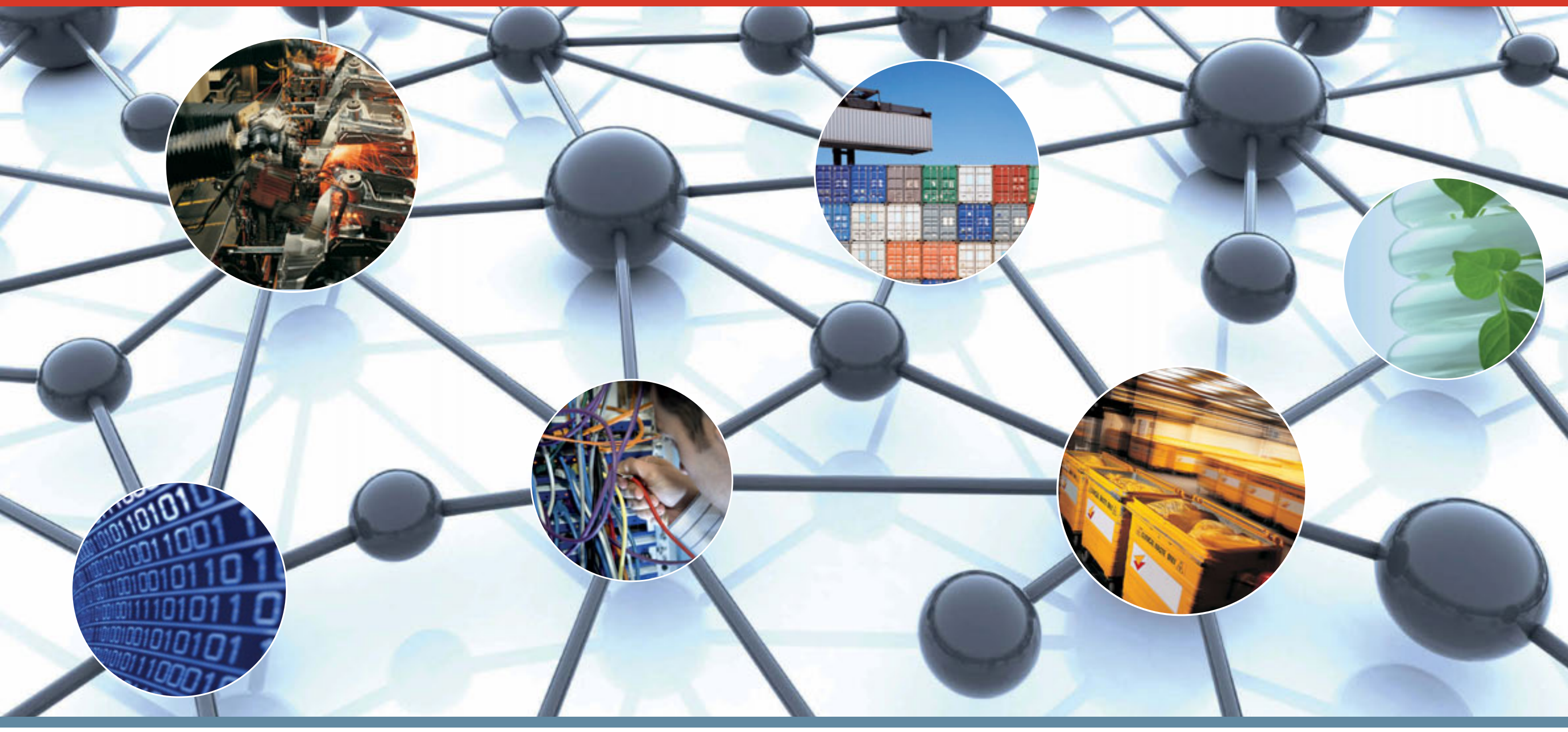

Emerging trends
in global manufacturing industries

IfM MANAGEMENT TECHNOLOGY POLICY

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIVERSITY OF CAMBRIDGE

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna, 2013

Acknowledgements

This report was prepared under the general guidance of Ludovico Alcorta, Director of the Development Policy, Statistics and Research Branch of UNIDO. The contributors to the report are Carlos López-Gómez, Sir Mike Gregory and Eoin O'Sullivan from the Institute for Manufacturing, University of Cambridge, and Afonso Carlos Corrêa Fleury and Leonardo Gomes, both from the University of Sao Paulo.

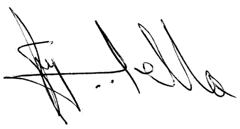
Foreword

The manufacturing sector, being the cradle of innovation and technical change, has always occupied an extraordinary position in the minds of economic policy-makers. The majority of innovations are introduced first and commercialized in this sector, making it the main engine of technical change and economic growth.

Technological change, in turn, is a crucial driver of competitiveness in the manufacturing industry, and is thus of particular interest for both business leaders and policymakers. In order to be able to design and implement policies that can support the growth and enhanced performance of the manufacturing sector of their respective countries, it is important for the policymakers concerned to have the necessary knowledge of how such technological change can be supported and promoted.

This publication is part of a series published by UNIDO to provide insights into current and future global trends that will influence manufacturing production in developing and developed countries in the years to come. It aims to assist policymakers in designing and implementing policies that can help their industries and countries gain a competitive edge in international markets.

I sincerely hope that the insights contained in this publication will be of value for policymakers, scholars and business leaders as they anticipate and adapt to the main forces shaping the manufacturing sector. At the same time, I invite the readers to actively participate in the discussion on the future of the manufacturing industry, which this publication series seeks to promote, and to contribute their experiences and opinions to the debate.



Kandeh K. Yumkella
Director General, UNIDO

Preface

There is renewed interest among policymakers in countries around the world in the role manufacturing plays within national economies, and a consequent focus on the potential of manufacturing strategies to enhance industrial competitiveness in the short, medium and long terms. There is also growing recognition that "business as usual" is not an option if national manufacturing competitiveness is to be achieved and sustained in the future. Critical manufacturing challenges and opportunities are driven by the increasingly complex and globalized nature of industrial systems, the dramatic reduction in manufacturing timescales and the acceleration of technological developments and innovation. Similarly, society's increasing demands, dwindling natural resources combined with increasing prices, diminishing availability of fresh water as well as adverse effects of climate change underline the necessity to use resources more efficiently in future industrial production.

This study, carried out by the Institute for Manufacturing, highlights significant trends and challenges for global manufacturing in the next 10-20 years. It is primarily informed by national exercises identified in major manufacturing economies addressing challenges and opportunities linked to the future of manufacturing. Rather than producing new primary data, the report aims to review and synthesize relevant existing work. Detailed industry-specific studies are outside the scope of this report. However, efforts have been made to provide representative insights into the dominant perceptions on the future of manufacturing systems internationally.

This study builds on the Institute for Manufacturing's ongoing research on the future of manufacturing and science and technology policy. The project has also benefited from the participation of researchers at the Production Engineering Department of the University of São Paulo. We hope this study proves both useful and timely for the manufacturing and policy community alike in a period of rapid change for global manufacturing systems, with major policy challenges for all regions around the world.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Contents

I. Introduction and overview

This report discusses significant trends and issues for global manufacturing in the next 10-20 years, based on a review of recent studies emerging in various manufacturing sectors around the world. While the studies analysed vary in terms of methodology, national context and stakeholder perspective, they all address critical questions related to the future of manufacturing systems. Special attention has been paid to those national exercises that have served as inputs for policy-making, and/or are recognized as influential for manufacturing stakeholders at the national level (i.e. industry associations, academia and individual firms). Such studies were identified in countries and regions including the European Union, Germany, United Kingdom, Denmark, Sweden, China, Republic of Korea, Australia, United States, Canada and Brazil. The key themes and observations emerging from our review are listed below.

A. Key themes and observations

- *"Moving in the dark"*. The changing nature of manufacturing activities is increasingly being recognized, and many countries around the world are carrying out forecasting and planning studies as inputs for the design of national manufacturing strategies and policies. While it is impossible to predict with precision what the future will look like, the most powerful contribution of this type of exercise is to create a proactive attitude in relation to the future. Prospective studies and innovative forecasting can provide insights into potential threats, opportunities, uncertainties and weaknesses in the manufacturing sector. Without such forward-looking analyses and reactive industrial policymaking, countries run the risk of "moving in the dark".

- *The future role of manufacturing in the national economy*. There is renewed interest across the range of countries our review analyses on the potential of manufacturing to address economic, strategic and societal challenges. Specifically, many studies discuss the importance of manufacturing for trade balance, improved productivity, economic, environmental and social sustainability and the development of production-related services. The contribution of production (and emerging production technologies) to tackle a range of social "grand challenges"—e.g. industrial sustainability and climate change—has also been emphasized. There are, of course, differences in the focus of different countries and regions, which often reflect national strengths or the interests of dominant industries within the economy. In the United States, for example, emphasis has been placed on the future role of manufacturing for technology development, creation of new industries and national security. In Europe, particular attention has been paid to the role of manufacturing as a driver of future economic recovery and as capturing economic value in the form of production-related jobs. In Asia, the focus has been on the challenges of the growing manufacturing base to achieve technological deepening and sustain future economic expansion. In Latin America, the emphasis has traditionally been on building on the abundance of natural resources to promote industrial upgrading and diversification.

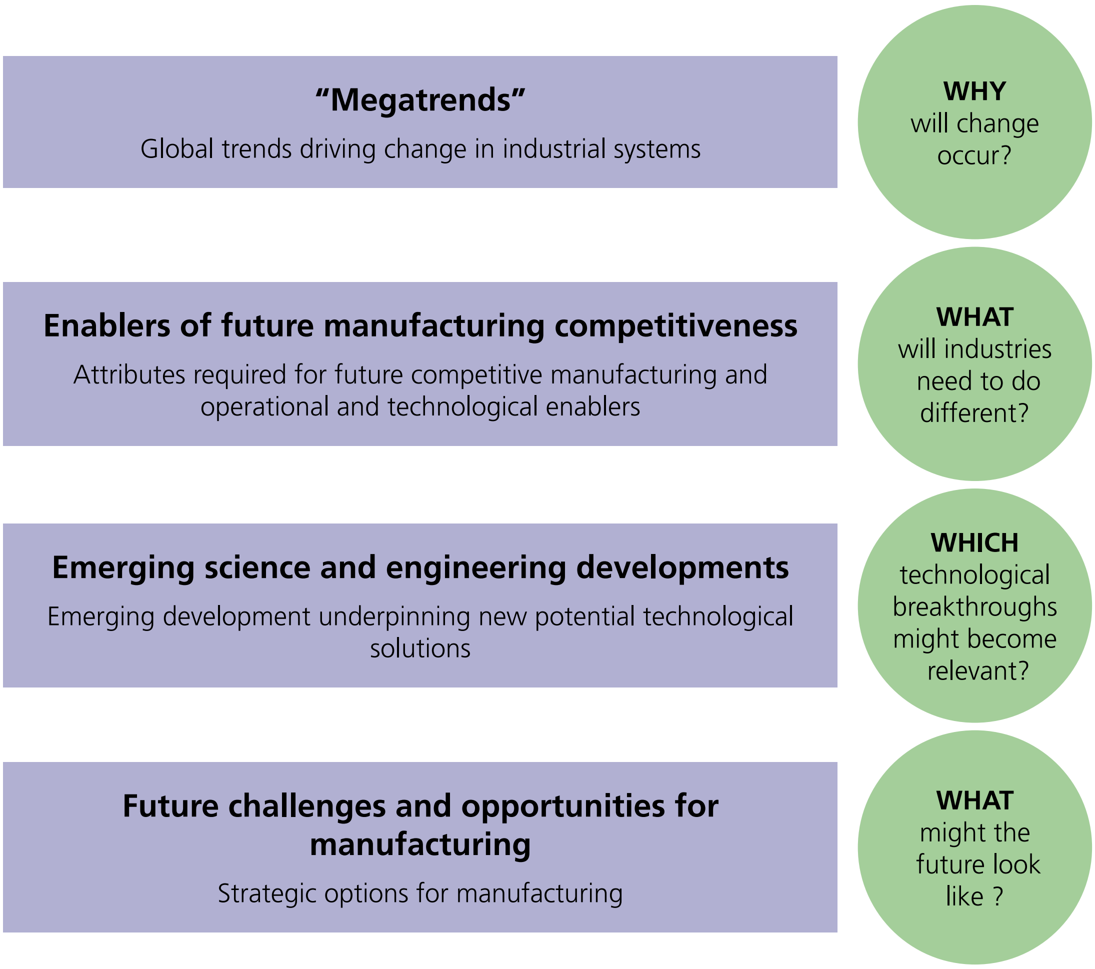
- *The systems-nature of manufacturing*. There is growing awareness across the countries included in our review of the profound transformations manufacturing activities have undergone over the last few decades in terms of structures, technologies, sectoral interlinkages and geographical boundaries. Manufacturing is increasingly understood as a system with 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. We argue that without conceptual frameworks and metrics that can account for the role of such production-related capabilities in modern manufacturing systems, it will be impossible to fully understand how economies might capture value from modern value chains, how to enhance manufacturing competitiveness or how to assess the impact of specific manufacturing-related policies.
- *The interdependence of manufacturing and future innovation*. Many countries have placed emphasis on the linkages between the production base and research activities and the role of this interaction for future innovation in manufacturing. For example, the fact that most of the R&D in the electronics industry—up to 90 per cent—is now being conducted in Asia is linked to the relocation of the production base from developed countries over the last few decades to this region. The significance of intersectoral linkages between manufacturing and services are expected to increasing in some manufacturing industries, with the emergence of new business models and manufacturing concepts.
- *Technological gaps*. This report argues that long-term industrial competitiveness may depend on countries' ability to build and upgrade production-related industrial capabilities and to address technological gaps in specific industries. We argue that such technological gaps can be found both in value chains of (commodity-based) "consumer industries" and in those of (capital equipment-based) "factory suppliers". While they are, to some extent, interrelated, we observe a growing recognition of the strategic importance of technological gaps in the latter, with many countries highlighting its linkages with manufacturing system elements including: manufacturing engineering R&D; systems integration engineering; advanced materials processing; measurement and testing; standards and regulation; prototyping and test bed engineering; and scale-up processes and engineering. These elements are part of what has been referred to as "industrial commons", the quality of which in many countries is increasingly related to the future viability of competitive national manufacturing systems.
- *Future opportunities*. This study offers a glance into potential future challenges and opportunities for manufacturing. Environmental technologies, industries based on emerging life science technologies, electric vehicles and key enabling technologies are only some of the areas identified as industries with high growth potential. This is a very limited list which will need to be expanded by future research. The report does, however, argue that conceptual frameworks

that account for the diverse elements of manufacturing systems are crucial for understanding how economies can increase manufacturing competitiveness, close technological gaps and elaborate strategies to capture value from modern value chains.

B. Categories for the analysis of emerging trends in global manufacturing industries

Different types of stakeholders have participated in the preparation of the exercises included in our review, ranging from research foundations and academic experts to government agencies and industry representatives. As a result, differences exist in national emphases, motivations and methodologies. We structure the findings from the exercises analysed into four broad categories to account for these differences. These categories are shown in Figure I and developed in the following sections of the report.

Figure I. Adopted approach for the analysis of emerging trends in global manufacturing industries



- *Megatrends*. This category (chapter II) includes major high-level, non-sector-specific, global trends affecting the evolution of manufacturing around the world. These "megatrends" are recognized as critical drivers in many countries, shaping future manufacturing challenges and opportunities. They include phenomena affecting industrial activity at the global and national levels: the increasingly complex and globalized nature of manufacturing; the drastic reduction in manufacturing timescales and associated acceleration of technological innovation; and the growing need for sustainable, resource-efficient production.

- *Enablers of future manufacturing competitiveness*. This category (chapter III) describes qualities and characteristics that, according to many of the exercises analysed, will trigger industrial development in the face of the above-described global trends and drivers. These are attributes that manufacturing industries—from the system (meso) rather than the firm (micro) perspective—will need to develop and sustain in order to remain competitive in the future. Some of the most evident qualities and characteristics that will be increasingly necessary in the future include resource efficiency and the ability to operate in multi-level value chains dispersed around the world and be constantly reconfigured. Furthermore, many countries have identified a number of organizational ("soft") and technological ("hard") production system solutions and innovations with the potential to underpin these qualities and characteristics. Some examples include: rapid prototyping methods, adaptive production processes and intelligent manufacturing control systems, as well as new organizational and business models.

- *Emerging scientific and engineering developments*. Chapter IV deals with scientific and engineering developments emerging out of the research and innovation base with the potential to provide innovative production systems solutions. Emphasis is placed on the solutions these technologies can provide to support specific production-related capabilities. Many countries have emphasized the potential impact of a number of technology areas in future manufacturing systems. They include: photonics, biotechnology, nanotechnology, microtechnology, information and communications technology (ICT) and advanced materials.

- *Global and regional high-growth industries*. Chapter V presents a number of industries that have been identified in many countries as having high growth potential as a result of the high-level global trends as well as emerging technological developments. Accordingly, changes that are not observable through current growth trends are likely to occur in the sectoral composition of manufacturing. Particularly, environmental technologies, electric vehicles, industries based on emerging life-science technologies and the so-called key enabling technologies have been identified by many countries as areas of high growth.

B.1. Limitations

The major limitation to our study was poor data availability. Additionally, it is worth keeping in mind that our work has mainly consisted of compiling and synthesizing existing work rather than producing new primary data. While our review is by no means comprehensive, efforts have been made to capture a representative selection of exercises carried out in important manufacturing economies (see annex). We believe, however, that the information presented here offers insights into the dominant thinking on the future manufacturing systems internationally.

II. “Megatrends” driving change in global industrial systems

This section presents an overview of major high-level, non-sector-specific trends and drivers affecting global industrial systems. While some effects of these “megatrends” are already visible today, they are expected to drive further change in global manufacturing activity.

The trends and drivers identified are not independent from each other. For example, globalization is driving the spread of technologies across the globe, while technological advances are allowing people to become more connected, thus creating a more globalized world. The trends and drivers must therefore be aligned not only with the background against which manufacturing systems will need to operate, but also with the factors defining future challenges and the sources of new opportunities.

A. Globalization

In today’s global economy, firms do not operate in isolation. Rather, competition increasingly occurs between interrelated firms or groups of firms that collaborate with one another, performing complementary activities to produce goods and services. This interconnectedness between nations and firms across borders has had major implications for global manufacturing systems, the reorganization of which is expected to deepen in the next few decades.

A.1. Offshoring and outsourcing

As production systems become more sophisticated and the world becomes more globalized, firms have adopted strategies that have increasingly involved the re-organization of value chains, both in terms of ownership boundaries and location for production. As a result, manufacturing activity has become more and more fragmented. Goods are increasingly created in a number of stages that take place across different locations and in different countries. Raw materials are obtained in one location; intermediate inputs, such as parts and components, are produced in another and the goods are then exported to yet a different location for further processing and/or assembly into final products. Today, there are many firms that produce goods without their employees having even touched the actual products (as is the case of Cisco with products such as routers and switches or Apple with phones). The restructuring of global industrial activity is reflected in the continuous growth of trade in intermediate[1] inputs over the last decade.[2]

It was typically believed that when production is fragmented internationally, developed countries would retain high-value adding activities and developing countries would concentrate in labour-intensive ones. However, it is far from clear whether this will hold in the future. There is growing concern in developed countries as indications are emerging that production-related, skill-intensive activities such as R&D, design and professional services are also being offshored to developing countries as part of the global reorganization of manufacturing (OECD, 2007). In fact, some estimates indicate that 90 per cent of all electronics R&D now takes place in Asia, in part because firms need volume production to be able to afford general R&D (ITIF, 2011). According to data from the United States Bureau of Economic Analysis, investments in R&D by United States corporations from 1998 to 2007 increased more than 2.65 times faster overseas than all corporate investment did domestically (ITIF, 2011). Indeed, our review reveals that many developed countries identify the potential move of high-value adding manufacturing activities to developing countries as one of the biggest challenges to national manufacturing competitiveness in the coming years.

A.2. Emerging regions

The development of global value chains has facilitated the rapid integration of emerging regions into the global economy, which are increasingly exerting competitive pressures on traditional manufacturing nations. In particular, China, India and Brazil have recorded very high growth rates of manufactured exports. These are leading countries and highly competitive exporters: India in software and IT-enabled services, China in skill-intensive manufactures and Brazil in agricultural products. Latin America is playing an increasingly important role as a supplier of raw materials and food to the world. Africa's potential as a supplier of raw materials in the future is becoming increasingly evident as well.

The analysis of containerized trade flows provides an indication of the changing landscape in global commerce. Trade increased from 13.5 million TEUs[3] in 1980 to 68.7 million in 2000 and to 138.9 million in 2010. In 1980, the major trade lanes were U.S.-Europe, U.S.-Asia and Europe-Asia. Inter-Asian trade was relatively minor. In 2010, intra-Asia was the largest trade lane, bigger than the Trans-Pacific trade (Goldman Sachs Investment Research, 2011). It is estimated

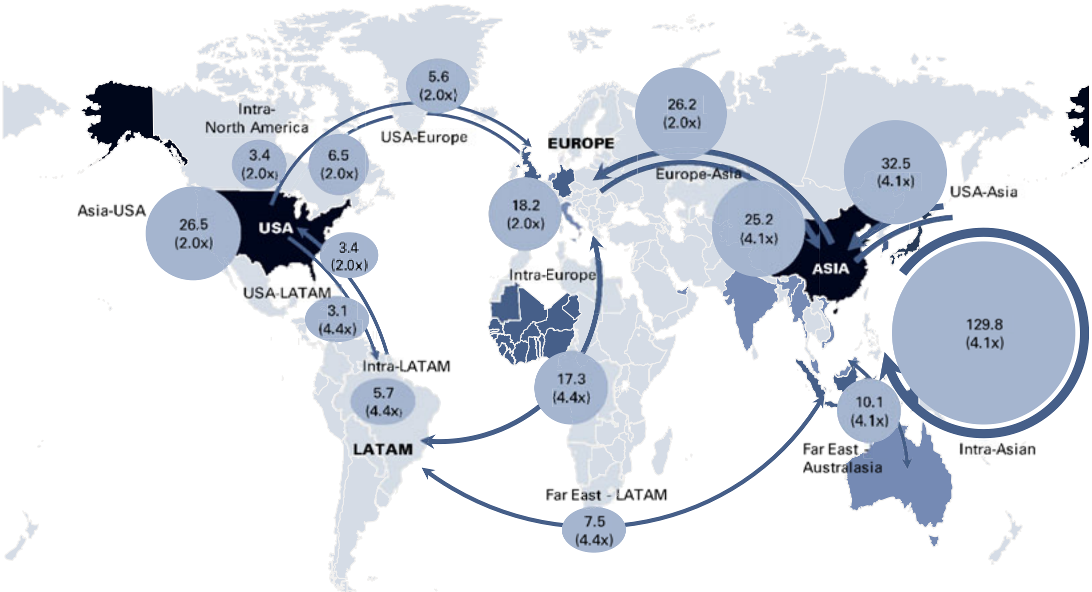
[1] An intermediate good can be defined as an input to the production process that has itself been produced and, unlike capital, is used up in production (Jovane, Westkämper, & Williams, 2009).

[2] Sturgeon & Kawakami (2010) found a 10-fold increase of world imports of intermediate goods in the last four decades (constant price data). Similarly, a recent study (Miroudot, Lanz, & Ragoussis, 2009) used historical trade data and input-output tables to study bilateral trade in intermediate goods and services in the OECD region. It found that intermediate inputs have remained relatively stable at around 55 per cent of goods trade and over 70 per cent of services trade during the period 1995-2007. This means that trade flows are dominated by products that are not consumed by the end user, but further transformed in other stages of the value chain at different geographical locations.

[3] TEUs: twenty-foot equivalent units, a standard-size container.

that intra-Asian trade could be nine times larger than U.S.-Europe trade by 2030 (figure II). The growth of intra-Asian trade is in part driven by the relocation of European and American manufacturing hubs to Asia to serve the regional market. Some new trade lanes are expected to gain importance; for example, Asia's contained trade with Africa, Latin America and Australia is expected to grow at rates well in excess of the global average (Goldman Sachs Investment Research, 2011). Latin America is expected to be one of the regions with the highest contained trade growth, though it will still have a relatively small global share compared to Asia.

Figure II. Containerized trade flows between regions of the world, 2030 (MN TEUs) vs. 2010 (2030/2010 x).



Source: Goldman Sachs Investment Research, 2011.

The following are some projections related to the future of emerging regions in the global economy:

- Growth projections for Brazil, the Russian Federation, India and China (BRICs) indicate they will collectively match the original G-7's share of global GDP by 2040-2050. No other countries are projected to rise to the level of China, India or the Russian Federation (United States Intelligence National Council, 2008).
- If current trends continue, China will have the world's largest economy by 2020 measured by GDP in purchasing power parity (PPP) terms. Looking at GDP at market exchange rates (MERs), the Chinese economy would still be likely to be larger than that of the United States before 2035 (PwC, 2011). By then, China could become the largest importer of natural resources and assume a key position in the debate on global climate change and environmental protection.

- India will most likely continue to enjoy relatively rapid economic growth and will increase its influence in international affairs (United States Intelligence National Council, 2008). It could also overtake the United States by 2050 on this PPP basis. On a MER basis, India could be the third largest economy in the world by 2050, well ahead of Japan and not too far behind the United States (PwC, 2011).
- The political and economic power of other countries such as Indonesia, Iran and Turkey is expected to increase (United States Intelligence National Council, 2008).

While the emerging regions have traditionally been considered factories of the world primarily associated with manufacturing assembly, they are building on their accumulated industrial base and know how and heavily investing in industrial upgrading. As a result, they are expected to play an increasingly significant role as global competitors and suppliers. In Asia, large-scale manufacturers are emerging as dominant players in the global value chains. Such is the case of the Hon Hai Group based in China, Taiwan Province, which with its subsidiary Foxconn, is considered the world's largest electronics contract manufacturer. Foxconn is reputed to produce 50 per cent of the world's electronic products (Future Manufacturing Council, 2011).

China, in particular, will continue to emerge as a major player in manufacturing in the Asian region and in the world. The country is developing a more advanced manufacturing sector through multiple strategies, most commonly involving foreign technology adoption. However, China is also intensifying efforts to promote its internal innovation and production capabilities, adopting a proactive role to promote indigenous innovation (see Trend G, External Industrial Policy Trends).

Latin America, for example, is investing in organizing and managing its global supply chain. Brazil is the largest economy in Latin America and its GDP growth has averaged 4 per cent over the last decade. Brazil overtook the United Kingdom's economy in 2012, becoming the sixth largest economy in the world; according to some estimations, it is expected to overtake France by 2014 and Germany by 2025 (PwC, 2011). Growth will, in part, be driven by increased oil production (new deep-sea oilfields will start operations) and by increased demand for Brazilian food and minerals by Asian countries. Additionally, Brazilian manufacturing industries are expected to play a more important role globally, as the government continues to establish a number of policies to promote domestic industrial capabilities.

B. Sustainability

There is increasing acknowledgment that sustainable manufacturing goes beyond the production stage of the value chain; it addresses the entire system of integrated components, energy and transportation required to assemble the final product and deliver it to customers (O'Sullivan, 2011). Sustainable manufacturing also extends across a product’s lifetime. Furthermore, there are significant societal pressures and a potential competitive advantage in addressing the sustainability agenda through a broader perspective—one that combines environmental, social and economic factors.

- *Environmental dimension*: Global efforts are required to reduce the impact of manufacturing operations on the environment. Manufacturing activities are energy-intensive and are responsible for creating pollutants (table 1). In the future, the environmental impact from production systems must be reduced to “near zero” (Teknikföretagen Production Research, 2008). The “near zero” impact can be achieved by producing more lightweight products, by using more environmentally friendly materials and by designing and implementing more energy efficient manufacturing processes and systems for disassembly and recycling. This calls for radical change in product design, production systems and the overall production process. Similarly, a growing number of environmentally conscious consumers are reducing their environmental foot-print, avoiding brands with poor environmental reputations and often willing to pay a premium for green products—all of which is opening new markets for businesses (Future Manufacturing Council, 2011).

Table 1. Pollutants resulting from manufacturing

Pollutant	Effect
Greenhouse gas (GHG) emissions from direct and indirect energy use, landfill gases	Global climate change
Emission of toxins, carcinogens, etc. including use of heavy metals, acids, solvents, coal burning	Human organism damage
Water usage and discharges, e.g. cooling and cleaning use, in particular	Water availability and quality
Electricity and direct fossil fuel usage, e.g. power and heating requirements, reducing agents	Depletion of fossil fuel resources
Land use, water usage, acid deposition, thermal pollution	Loss of biodiversity
Emissions of CFCs, HCFCs, nitrous oxides, e.g. cooling requirements, refrigerants, cleaning methods, use of fluorine compounds	Stratospheric ozone depletion
Land appropriated for mining, growing of bio-materials, manufacturing, waste disposal	Land use patterns
Material usage and waste	Depletion of non-fossil fuel resources
Sulphur and NOx emissions from smelting and fossil fuels, acid leaching and cleaning	Acid disposition

Source: (STPI, 2010)

- *Social dimension*: Manufacturing can only generate welfare for citizens if manufacturing environments provide adequate workplaces for the residents

(EFFRA, 2011). There are growing concerns on the need for well-paid, secure and quality jobs in safe working environments as a company's competitiveness is based on both the competitive edge of individuals' and the staff's collective average competence. A good working environment is therefore important and the systems must be designed to make human-human and human-technology interaction efficient (Teknikföretagen Production Research, 2008).

- *Economic dimension*: There is increasing pressure to achieve economic growth, especially in the developing world, while reducing consumption of scarce resources, including energy and water, and minimizing waste. Economic sustainability requires the use of resources to the best advantage while consistently achieving profits. A key message that emerges from our review is that environmental and social sustainability can only be achieved if manufacturing is competitive and able to generate the income required to pay knowledge workers and to invest in environmentally friendly and worker friendly factories (EFFRA, 2011).

C. Demographics

Demographic changes in coming decades will shape the future of manufacturing. Changes in the size, composition and educational aptitude of the workforce are expected to pose a significant challenge to industrial competitiveness.

C.1. Ageing population

Particularly in developed countries, the ageing of societies coupled with the potential lack of a skilled young workforce could have major consequences on labour supply and skill shortages, future markets and products, hiring strategies, welfare systems and on the organization of human work. Many countries recognize that a response to this trend must be coordinated among all areas of public policy and the private sector. Some implications of an ageing population on the global economy in the future include the following:

- *Decreasing labour supply*. In many countries, labour supply is expected to decrease due to the retiring workforce. For example, it is estimated that the working age population (15-64 years) will peak in Europe in 2012, after which it will begin to decrease as the "baby boomer" generation retires. Thereafter, the "ageing effect" will outstrip the increase in participation rates, resulting in a slight but continuous decline of total EU labour supply (DG Enterprise and Industry, 2010).
- *Widening skill gap*. The manufacturing industry in many countries will face a widening skill gap, driven by the retirement of a greater number of experienced employees each year, which cannot be matched with the hiring of younger,

unqualified and inexperienced employees. This situation will affect the way companies hire, train, retrain and compensate their future workforce.

- *Increased spending on welfare and health system*. Besides the challenge to industry, the combination of a smaller working population and a higher share of retired people will place additional strains on the welfare and health systems in a number of countries (DG Enterprise and Industry, 2010). This means an increase in the “dependency ratio”, as there will be a larger number of people claiming pensions and medical services and less people working and paying taxes. As a consequence, those employed might be required to pay higher taxes.

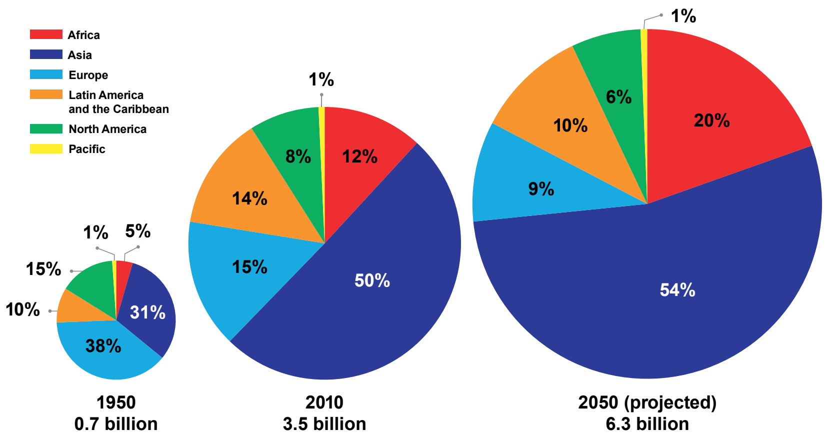
C.2. Changing patterns of international demand

Globally, the emergence of middle and upper classes in the developing countries is expected to dramatically shift market concentration. By 2015, 130 million households representing 460 million residents in Brazil, China, India, Indonesia, Mexico, the Russian Federation, South Africa and Turkey will have “graduated” from poverty to the middle class (BCG, 2010). The OECD concludes that over the coming decades, Asia’s emerging middle class will be large enough to become one of the main drivers of the global economy. In fact, Asian savings may fall and redress current global imbalances to some degree (OECD, 2010). The expected shift in demand may well disrupt existing supply chains.

D. Urbanization

The sustained flow of people from rural areas and smaller towns to major cities combined with the deceleration of rural population growth will result in an increase in the share of population living in urban areas. Today, more than half of the world’s population already lives in cities and according to the United Nations, this figure will increase to 72 per cent by 2050 (United Nations, 2011). The fastest growth will be witnessed in large cities in Africa and Asia. It is estimated that the urban population in Asia will increase from 1.36 billion to 2.64 billion by 2030, while in Africa it will rise from 294 million to 742 million, and from 394 million to over 600 million in Latin America and the Caribbean (United Nations, 2011).

Figure III. World urban population in 1950, 2010 and 2050



Source: United Nations, 2011.

This process of rapid urbanization poses serious, complex challenges such as lack of sufficient housing, transport congestion and environmental degradation. In addition, this trend calls for initiatives to create jobs near cities with population agglomerations and to design factories that are able to operate in the urban environment. Future global challenges driven by increasing urbanization will translate into the following manufacturing requirements:

- *Mobility solutions*. Transportation congestion mainly affects urban areas which are also challenged by problems such as inner city decay, sprawling suburbs and concentrations of acute poverty and social exclusion (Jovane, Westkämper, & Williams, 2009). The rise in global urbanism is accompanied by an increased demand for greener mobility and transportation solutions, which again will be underpinned by innovative, cleaner, greener products, equipment and systems (Future Manufacturing Council, 2011).

- *Housing solutions*. These social and demographic changes are leading to a higher demand for housing. However, building new affordable homes in urban areas is difficult, as many cities display sharp inequalities in housing provision. Implementing a modular system and using new construction materials will allow for rapid construction of affordable housing. Furthermore, the need to house increasingly urbanized populations in a sustainable fashion will create demand for products and technologies that enable greener buildings and infrastructure (Future Manufacturing Council, 2011).

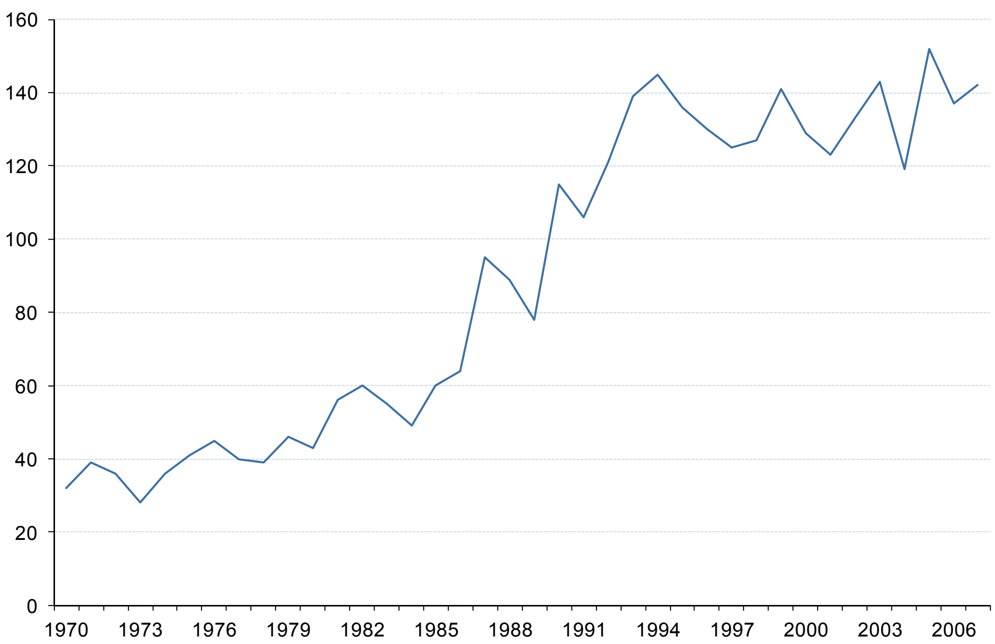
- *Environmental solutions for cities*. Due to increased urbanization and environmental degradation, cities will increasingly face serious challenges such as deteriorating water quality, excessive air pollution, noise, dust and heat as well as problems with waste disposal. There is thus a need for low emission vehicles, efficient "inter-model" transportation systems, pedestrian friendly neighbourhoods and buildings that minimize their environmental impact such as gas emissions from cooling and heating.

E. Threats to global stability

Although many companies have introduced risk management initiatives, recent events have demonstrated that risks can have a domino effect and unexpected consequences that cannot be mitigated by one organization alone. Geopolitical disruptions are difficult to control in the short term, with limited opportunities for industries to influence outcomes. A dual approach of both risk reduction and increased network resiliency will be required to address uncertainty in the future (WeF, 2012).

- *Natural disasters*. Natural phenomena will continue to pose latent threats, with the potential to affect regions and nations and disrupt even the best managed supply chains. They can damage production facilities, delay shipping schedules, interfere with production and affect companies' ability to deliver timely, high quality products. They might also lead to shortages of several consumer and industrial products, which could, in turn, result in inflation. As shown in figure IV, the number of natural catastrophes registered globally has increased significantly over the last few decades. Given the current geographical dispersion of manufacturing activity, a natural disaster in one country can have profound effects in the functioning of global value chains (see box 1).

Figure IV. Number of natural catastrophes registered globally



Source: Goldman Sachs Investment Research, 2011.

Box 1. Effects of Japan's twin disasters in some global value chains

The twin disasters in Asia in 2011 had a detrimental effect on the global supply chain, which reached far beyond the continent. According to some estimates, the economic cost of the earthquake and tsunami in Japan was around US$ 210 billion and the losses as a consequence of last year's floods in Thailand amounted to US$ 30 billion. Some examples of the disruptions in manufacturing as a consequence of these disasters include:

- Japan's major automobile manufacturers are expected to produce about 400,000 fewer vehicles domestically as a result of the earthquake and tsunami (Nanto, Cooper, & Donnelly, 2011).
- Toyota and Honda were severely hit, resulting in a decrease in their production and volume of sales. As a consequence, Toyota lost its position as the top global automobile manufacturer in 2011 to General Motors (Munich Re & Thailand Insurance Commission, 2011).
- A Hitachi factory north of Tokyo that produced 60 per cent of the world's supply of airflow sensors was shut down. This caused General Motors to shut a plant in Shreveport, Louisiana for a week and Peugeot-Citroen to cut back production at most of its European plants (Nanto et al., 2011).
- Two Japanese plants accounting for 25 per cent of the world's supply of silicon wafers for computer chips were closed (Nanto et al., 2011).
- Nippon Chemi-Con Corp., the largest producer of aluminium electrolytic capacitors—used in everything from computers to industrial equipment—had to close its four Japanese factories. It announced its intention to boost production at ten overseas bases, including factories in Indonesia, Malaysia and China (Nanto et al., 2011).

Another example in the high-tech industry is Intel, which claims that it lost around US$ 1 billion in sales in the last quarter of 2011 due to the floods in Thailand, as many computer OEMs did not buy its chips because they were unable to source the hard drives (which are mass produced in Thailand) to produce the computers.

- *Armed conflicts*. Conflict-affected areas may potentially have adverse impacts on a company's operations and/or on its relationships with third parties, including suppliers or other actors in the supply chain (OECD, 2011). In addition, such conflicts may cause severe disruptions of the main transportation routes or production hubs. According to the International Energy Agency, escalating violence in Libya in March 2011 meant that up to two-thirds of Libya's oil production would not make it to market. Maritime piracy is an increasing concern for supply chain professionals and transport providers, and is estimated to cost the international economy between US$ 7 billion and US$ 12 billion per year (WeF, 2012).

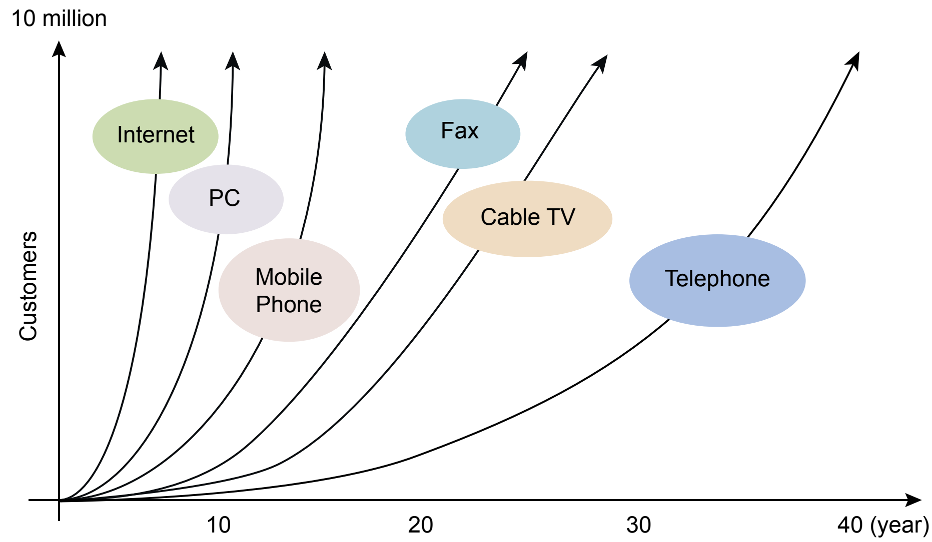
- *Terrorism and security*. The consequences of growing security concerns are expected to be an increased investment in the defence and security industry. While businesses are concerned that a security disruption may affect a critical production or distribution hub, they are also concerned that fear of such events occurring may trigger legislation that could have an equally disruptive effect (WeF, 2012). This is best illustrated by the cumulative increase in expenditure of over US$ 1 trillion in United States domestic homeland security since 9/11, as well as a range of new industry regulations and requirements across supply chains and transport networks (Mueller & Stewart, 2011).

F. Accelerating product life cycles

Time is an increasingly critical factor in today’s manufacturing environment. Rapid innovation is expected at all stages of product realization. More efficient supply chains, rapid technological advances (including the accelerating pace of science and technological innovation), and changing patterns of demand are driving ever shorter product development cycles. Accelerating product life cycles are expected as a result of issues, including:

- *Accelerating rate and pervasiveness of technological innovation*. As consumer attitudes change and trade becomes more global, new products and technologies have the potential to reach a larger number of users in reduced periods of time (figure V). For example, some estimates predict that while it took the telephone almost 70 years to reach 80 per cent penetration in United States households, it will take only 12 to 15 years (that is, 5 to 7 years from today) for smart phones to reach the same level of penetration (Dediu, 2012).

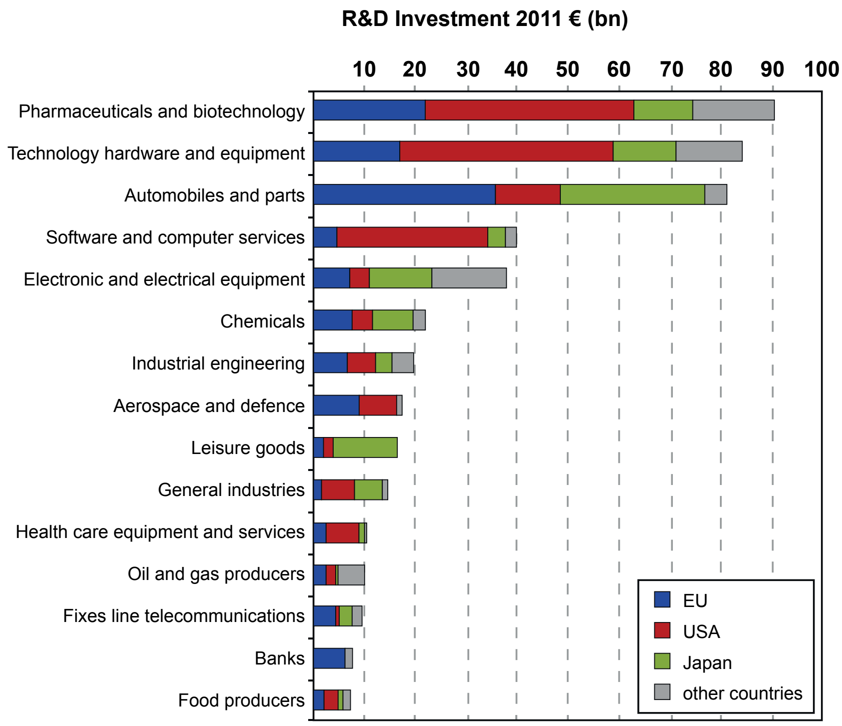
Figure V. Technology adoption rates



Source: Yim, 2011.

- *Emerging science and engineering developments*. Increased investment in a number of prioritized science and technology areas is set to continue with a potential impact on a range of manufacturing industries as well as sectoral composition. As a reference, the five most R&D-intensive industries (pharmaceuticals and biotechnology, hardware technology and equipment, software and computer services, leisure goods and health care equipment and services), all with an average R&D intensity of over 6 per cent, contributed to about 70 per cent of total R&D for the United States, and about 36 per cent of total R&D for both the EU and Japan in 2009 (European Commission, 2009).

Figure VI. R&D ranking of industrial sectors



Source: European Commission, 2009.

G. Changing consumer habits

It is expected that general prosperity and income increases in emerging countries and regions in the future will lead to a rise in consumption of basic consumer products and other product categories (BCG, 2010). For example, education is becoming a high priority for many citizens of emerging markets. In the housing market, private ownership will grow. An increased number of people will demand individualized products and services which will bring about new challenges for product development and manufacturing systems.

Not only is the population of emerging cities rapidly increasing, so is their disposable income. By 2030, demand from the global middle class is likely to grow from US$ 21 trillion to US$ 56 trillion, with 80 per cent of the growth coming from Asia (table 2). Emerging markets also hold tremendous potential for luxury goods. With the rapid growth of its millionaire households, China is expected to become the world's largest luxury market in the next few years (BCG, 2010).

Moreover, many consumers with less disposable income in emerging markets are starting to develop brand preferences as their income increases. This represents a major opportunity for manufacturers of higher value-added products and services, as these previously unattainable products are becoming more widely used.

Table 2. Spending by the global middle class, 2009 to 2030
(millions of 2005 PPP dollars)

	2009	2020	2030
North America	5 602	5 863	5 837
%	26%	17%	10%
Europe	8 138	10 301	11 337
%	38%	29%	20%
Central and South America	1 534	2 315	3 117
%	7%	7%	6%
Asia Pacific	4 952	14 798	32 596
%	23%	42%	59%
Sub-Saharan Africa	256	448	827
%	1%	1%	1%
Middle East and North Africa	796	1 321	1 966
%	4%	4%	4%
World	21 278	35 045	55 680
%	100%	100%	100%

Source: OECD, 2010.

H. External industrial policy trends

Many studies expect that establishing a competitive manufacturing sector will continue to be a priority for many countries in the future. Governments’ desire for intervention is expected to increase, both in developed and in developing countries. In developed countries, increasing concerns about the loss of production jobs and trade imbalances have led governments to establish long-term public investments to support manufacturing, most notably through R&D funding programmes. There is a growing number of official white papers in Japan, Europe and the United States that recognize the need of government support for manufacturing in the future, and a growing number of industry support programmes are being announced.

Emerging countries such as China and the Russian Federation have adopted the use of sovereign wealth funds (SWFs), ownership of state-owned enterprises

(SOEs) and the promotion of national champions, following an economic model that has been referred to as "state capitalism" (US Intelligence National Council, 2008). Along with cash-rich Gulf States, these countries are elaborating plans to diversify their economy, assigning particular importance to the development of an internationally competitive manufacturing base. Given the large scale of government investments in manufacturing, companies in emerging countries might emerge as global players and disrupt global market relationships.

Several leading and emerging countries are currently heavily investing in the creation of a critical mass in enabling technologies. Examples of such investments are (High Level Group on Key Enabling Technologies, 2010):

- The United States *National Nanotechnology Initiative* with a budget of €1 billion a year (matched by industry);
- The US$ 2.6 billion annual funding for SMEs in the *Small Business Innovation Research* (or SBIR) programme in the United States;
- *RusNano* with approximately US$ 5 billion, which represents 50 per cent of the Russian budget for nanotechnology;
- Sixteen mega projects in China with an investment of up to €10 billion per project;
- Japan's *Industrial Cluster Project* with €150 million of public funding in 2009;
- In Europe, France has recently announced that it will raise €35 billion to fund strategic investments, with a special focus on biotechnology and nanotechnology.

III. Enablers of future manufacturing competitiveness

In the context of rapidly changing conditions associated with the megatrends described in the previous chapter, it will not be "business as usual" for manufacturing in the future. Policy documents in many countries have emphasized that industries will need to enhance or develop new qualities and characteristics if they are to remain competitive. For example, globalized value chains and changing consumer habits will demand increasingly flexible production systems, capable of minimizing the effect of disruptions in the value chain and to adapt production quantities according to demand fluctuations. Similarly, changing customer preferences might require shorter innovation timescales in order to realize the required product and process modifications in a timely manner. We divide the qualities and characteristics most commonly cited in the exercises analysed into six categories: *(a)* distributed manufacturing, *(b)* rapidly responsive manufacturing, *(c)* complex manufacturing, *(d)* customized manufacturing, *(e)* human-centred manufacturing, *(f)* sustainable manufacturing and innovation-receptive manufacturing.

This chapter identifies organizational and technological solutions and innovations with the potential to enable industrial development (organizational relates to "soft" issues such as the management of manufacturing operations while technological refers to "hard" issues related to production processes and technologies). We divide these solutions, concepts and innovations according to the six categories listed above, though some of them could belong to more than one category. For example, ICT solutions for the management of production systems can facilitate the realization of both distributed and flexible manufacturing systems. While not necessarily new, these solutions, concepts and innovations are expected to become more widely adopted in the oncoming years.

We do not suggest that all manufacturing firms will need to exhibit all of the above qualities and characteristics or implement all the discussed organizational and technological solutions in order to remain competitive. Requirements will vary from firm to firm depending on a number of factors such as the industry's own internal dynamics and the firm's position in the value chain. Therefore, rather than offering a description of a competitive firm in the future, this chapter could be seen as an overview of what competitive industrial systems as a whole are expected to look like in oncoming years. The lists of qualities, characteristics and solutions presented here is by no means comprehensive, but it does offer an overview of the dominant thinking about the future enablers of competitive manufacturing systems in many important manufacturing nations.

A. Distributed manufacturing

In a more globalized world, manufacturing systems increasingly face the challenge of managing operations across vastly distributed production environments. They need to adapt to a global customer base and recognize arising market opportunities quickly. Some of the required qualities and characteristics identified by international studies for managing distributed manufacturing systems include:

- *Dynamic collaboration across extremely complex multi-level, reconfigurable supply chains*. The process of globalization will increasingly result in tightly interlinked international value chains (DG Enterprise and Industry, 2010). As competition is expected to increasingly occur between groups of firms rather than between individual firms, growth in manufacturing will be enabled by new organizational competencies in complex structures often spanning across several companies and/or countries (Jovane et al., 2009). Simultaneous and coordinated operations will be necessary to make individual companies competitive, as value added will be increasingly achieved through synergies between supply chain actors (Teknikföretagen Production Research, 2008). Building successful dynamic networks will require close interaction between component suppliers, engineering service providers, production equipment manufacturers, producers and, of course, customers.
- *An agile supply chain*. Partnerships with highly competent firms will be crucial for the success of any manufacturing company. An agile supply chain will require a radical change from the use of high inventories and order quantities based on maximum capacity utilization towards a more predictive, make-to-order approach. The main characteristics of an agile supply chain are speed and flexibility necessary to achieve the lead times shifting market requirements give rise to. This will entail shorter production lead times, minimal inventory and related costs, increased production capability, improved manufacturability and product quality as well as reduced resource consumption.
- *Transparent provision of information on products and processes*. In a rapidly changing world, the ability to obtain and act upon real-time information will be increasingly crucial for manufacturing systems to stay competitive. A key requirement is thus the acquisition of sound, relevant and timely information as an input for decision-making.

A.1. Organizational and technological solutions, concepts and innovations for enabling distributed manufacturing

- *ICT solutions for distributed manufacturing*. Continuous access to vast amounts of information in manufacturing systems requires new methods to process and utilize it. A distributed manufacturing model would allow products to be designed in one location using software solutions which enable real-time sharing of the designs with production sites in various other locations.

Enhanced collaboration will allow companies to exchange knowledge and facilitate flexibility across the value chain, interact across internationally distributed settings and ensure the integration of information flows between the firm and its supply chain partners. The principal drivers of such arrangements are higher shipping costs and consumer demand for customized products while the principal enabler would be improved manufacturing equipment and software (Government Office for Science, 2010).

- *Grid manufacturing*. Distributed manufacturing requires the integration of several types of resources which may be located in different regions, enterprises and organizations along the value chain in order to gain more flexibility against disruptive business environments. Grid manufacturing is identified as the next generation solution for addressing bottlenecks in networked manufacturing. It emulates the principles of grid computing—characterized by cooperative resource sharing—to enable dynamic and unlimited resource accessibility beyond rigid company boundaries. Grid manufacturing aims at enabling the use of networked and distributed manufacturing resources in order to: *(a)* support the collaborative planning, operation and management of manufacturing; *(b)* respond to the emerging challenges such as innovation, speed and flexibility (Jovane et al., 2009).
- *Computing systems, pervasive computing and embedded platforms*. The migration of ubiquitous computing into the manufacturing world represents a new challenge in manufacturing engineering. The manufacturing engineering community and enterprises need such technology to collect and use production information from a globally distributed factory in real time. This ubiquitous environment for manufacturing engineering needs to economically provide diverse communication functionalities to interface with existing (e.g. Process I/Os, serial communications and fieldbus) and new (e.g. industrial wireless Ethernet, RFID, USN (Bluetooth & Wi-Fi) data processing and decision-making functions. It is also essential for the new environment to use tether-free Internet technology.

B. Rapidly responsive manufacturing

Manufacturing firms will need to be able to quickly respond to and take advantage of changes in conditions, customer preferences, innovation and social requirements. Some of the qualities and characteristics required to achieve rapidly responsive manufacturing as identified in our review include:

- *Agile, adaptive, responsive and robust manufacturing*. To stay competitive, manufacturing companies must be able to react to unpredictable market changes, shorter "market windows" (which refers to the time that a company has to launch a new product into the market before the competition does in order to attain first mover advantage) and rising product development costs. Until now, obtaining a leverage of ± 30 per cent in production output was considered challenging. However, in order to respond to growing responsiveness challenges, the ability to deal with volume changes of

± 70 per cent in individual product groups should be attainable in the future (German Academy of Sciences, 2011). Therefore, manufacturing firms need to rethink their production systems to more rapidly respond to customer requirements and to better manage production capabilities.

- *Flexible production systems and supply chains flow*. The volatility of the global environment has led to major changes in the traditional manufacturing supply chains affecting decisions related to production levels, raw materials supply strategies and transportation capacity. Manufacturers will need to make supply chain-related decisions more quickly and flexibly in the face of more volatile demand. For example, they will need to consider relocating production to places where economies of scale can be achieved, renegotiate contracts and consolidate distribution channels faster when transportation costs rise above the acceptance levels
- *Rapid product realization*. For many products, the time from idea to full-scale production is now only one-third of what it was ten years ago (Teknikföretagen Production Research, 2008). Improving the path from concept to commercial viability is therefore an important challenge for future manufacturing competitiveness. Companies able to drastically reduce the time from customer demand to delivery will gain significant competitive advantage. Rapid new product realization requires, among other things, the use of emerging technologies and concepts to shorten product development cycles and the ability to act as a catalyst for the interaction of all actors involved from the initial concept to the final product. Tightly integrated design, tests, and validation across vastly distributed production environments will facilitate the transfer of collective knowledge.

B.1. Organizational and technological solutions, concepts and innovations for enabling rapidly responsive manufacturing

- *Supply chains will need to be more flexible, easier to reconfigure and more responsive*. For example, they will need to consider relocating production to places where economies of scale can be achieved, renegotiate contracts and consolidate distribution channels faster when transportation costs rise above the acceptance levels. Some companies are establishing supply chain "war rooms" to make faster decisions across functions (McKinsey, 2009). Such teams consist of leaders from production, procurement, logistics and sales departments and meet weekly or even daily to devise near-term operational plans.
- *New configuration system concepts and technologies (flexible and reconfigurable manufacturing systems)*. Traditional manufacturing systems do not correspond to the requirements of product design in the twenty-first century: a reduction in the product life cycle and increased demand for new and more complex product functionalities. Thus, intelligent manufacturing systems are designed to address these issues and to take into consideration both the economic as well as the engineering factors required to produce different product families within the same system, in the shortest time and at

the lowest cost without sacrificing product quality. The manufacturing paradigm focuses on two systems: flexible manufacturing systems (FMS) and reconfigurable manufacturing systems (RMS). RMS and FMS have different goals. FMS aims at increasing the variety of parts produced while RMS's objective is to increase the speed of responsiveness to markets and customers. RMS is also flexible but only to a limited extent (Malhotra, Raj, & Arora, 2009). Normally, FMS can be adapted, adjusted or modified to produce different products at different volumes of production, however, they are not designed to manage the production of customized products. Therefore, RMS is specifically designed to address the "customized flexibility" shortcomings of the FMS and the implementation of knowledge in the operation systems. RMS is designed for rapid change in structure in order to quickly adjust to production capacity and functionality within a product family in response to changes in market requirements (ElMaraghy, 2005). They are designed to have a high performance level and aim at offering the capacity that is needed when it is needed. Reconfigurable systems have the following characteristics: *(a)* modularity—components are designed in modular standardized units; *(b)* integrability—system components are designed to be easily integrated with other modules *(c)* interchangeability—the system allows for quick switches between the different sets of product requirements *(d)* scalability—the system is able to quickly and cost effectively change its capacity. Many aspects of such manufacturing systems are important for research challenges, and it is likely to create a need for innovation in design, production and service delivery.

- *Cost simulations systems* will facilitate the development of marketable products.

C. Complex manufacturing

Due to the increasing fragmentation of manufacturing activity, the growing mix of product requirements and the accelerated rate of technological innovation, manufacturers will face the need for ever more complex manufacturing designs, products, processes and operations. Some of the required qualities and characteristics that international studies have identified to operate in complex manufacturing systems include:

- *Affordable high-performance production tools*. In the future, manufacturing is expected to be characterized by an increasing complexity of products and production processes. Thus, high-performance production tools must be affordable for the relevant actors in the production system. Most manufacturers of complex systems no longer support in-house machining operations. Instead, they outsource such activities to specialty machine shops which fabricate components in accordance with their specifications. However, this specialized industry is dominated by a high number of small, unbranded players that are typically "in no position to develop sophisticated flexible manufacturing processes" (STPI, 2010, p. 2-3).

- *Integration ability*. The likelihood of success of next-generation products increasingly results from the interaction of technologies. The development of more sophisticated products will be based on the interdisciplinary cooperation of the technical sciences. This applies in particular to the cooperation among the engineering, material, natural and computer sciences (German Academy of Sciences, 2011).
- *Improvements in the usability of advanced technology*. The advanced technology used within a manufacturing company often fails to achieve its real potential because of inadequate usability. Technology is often merely employed to correct human error, failing to see human capabilities and human knowledge as a key resource. A more thorough integration of humans with technology and the improvement of cooperation between humans and machines are required to achieve synergy effects.

C.1. Organizational and technological solutions, concepts and innovations for enabling complex manufacturing

- *Rapid engineering and production of integrated high-confidence cyber-physical products and systems*. The merger of physical systems and processes with networked computing has led to the development of cyber-physical systems. Cyber-physical systems or products are engineering concepts developed to create adaptive and predictive processes and products for enhanced performance and decision support such as diagnosis and prognostics. Their applicability is broad, ranging from medical devices, traffic and control safety, avionics, robotics, environmental control and advanced automotive systems to defence systems. As they are not operated in controlled systems, they must be flexible enough to respond and adapt to unexpected conditions. Furthermore, the engineering and human elements should be completely integrated to enable the desired synergy effects.
- *Manufacturing control systems*. Modern manufacturing control systems must respond quickly to continuous changes in the next generation responsive factory. Within traditional manufacturing, control system programming is time consuming. The development of new models of control systems which have to provide control and diagnostic codes, enable the network architecture, data mapping, control and diagnostic system to be designed and integrated in a unified and single tool, represent the main research objectives in this area. The scientific activities and research steps consist of creating a customized process control and quality data interface system to network stand-alone pieces of manufacturing equipment, such as PLCs, robots, process machinery and test stations at all levels of the next generation responsive factory, from the network of factories to manufacturing processes, respectively.

D. Customized manufacturing

It is likely that there will be an increasing demand for personalized products and services over the next 20 years, with the related need to produce an increasingly heterogeneous mix of products in small or large volumes (Government

Office for Science, 2010).The ability to manufacture a customized product at different sites may overcome the drive towards commoditization and economies of scale in some sectors (Government Office for Science, 2010). From the design and production perspective, manufacturers will need to respond very quickly to a much wider variety of product specifications. To address these "mass customization" challenges in the future, some of the required qualities and characteristics identified in our review of international exercises include:

- *Competitively affordable customized production*. With constant changes in product volumes and mix, manufacturing firms will have to respond to a much wider range of product specifications in shorter time frames at an affordable price. Increased complex product functionalities are translated into additional pressures to produce individualized goods and services with a manufacturing process that is cost-effective (STPI, 2010).
- *Customization for local and global competition*. The driving forces for new products will be found both at the global and local levels. In certain geographical locations, local regulations and market needs will drive the demand for specific product characteristics. Meanwhile, the increasing global availability of technologies will allow developing countries to compete globally (EFFRA, 2011).
- *Product usability for groups with special needs*. Disabilities and ageing require different types of interaction between people and products that take account of all product characteristics—especially the hazardous ones—as well as people's limitations to use them. Although special needs are addressed in several standard bodies, there is no standardization process thus far which covers all the needs of customers of all ages. As a result, product designs do not usually take the specific requirements of seniors or people with disabilities into account.
- *Production for the world's population*. Currently, manufacturing firms only supply one-fifth of the world's population with high-tech products. Clearly, the products must meet other requirements than those they typically do today if they are to reach the populations of the poorer markets (German Academy of Sciences, 2011).

D.1. Organizational and technological solutions, concepts and innovations for enabling customized manufacturing

- *Technological and organizational visions for customized manufacturing*. Emerging technological solutions will need to be adopted to ensure the flexibility and permanent adaptation required in production systems. Advanced manufacturing techniques such as additive manufacturing and laser processing can help create complex, custom products and replacement parts that are needed quickly in low volumes (German Academy of Sciences, 2011). Increasingly, powerful computers, high-speed networks and even social media can provide nearly instantaneous information on product requirements, characteristics and performance throughout the value chain (German Academy of Sciences, 2011).

- *Service-oriented*. In order to increase their marketability, manufacturers are adopting new strategies by attaching services to their final products. Thus, a new manufacturing paradigm is emerging, so-called service-oriented manufacturing. High-capital investment companies are providing their customers with a range of services related mainly to product operations such as maintenance, upgrading, recycling and disposal. They are even moving forward by incorporating services into the final product—"coupled product and service" (Yakimov & Woosley, 2010, p. 16). Such innovative business models require virtual enterprise environments and a dynamic network of companies continuously moving and changing in order to afford increasingly complex compositions of services (EFFRA, 2011).
- *Technological and organizational visions for customized manufacturing*. Despite the advantages offered by intelligent manufacturing systems, it is important to mention that their implementation requires increased efforts to maximize its benefits. Such efforts go beyond the technical areas and targets the organizational and staff levels as well. Therefore, this transformation process must be planned and effectively managed and should address the following areas: *(a)* harness human flexibility and creativity; *(b)* accurately model humans and their interactions with machines and systems; *(c)* optimum design of harmonized human/ machine/ manufacturing systems which allows for effective and profitable co-existence and cooperation; *(d)* develop methodologies to deal with quality issues in hybrid human/machine systems (ElMaraghy, 2006).
- *Industry-specific solutions*. Some examples of personalized production in specific industries include the following:

    Personalized medicine is expected to improve its efficiency to prevent, diagnose and treat disease by using a person's genetic or other information. Many researchers are looking towards tailored health-care strategies and cell-based therapies to better target diseases. However, the required manufacturing technologies that meet the regulatory and economic requirements for successful commercialization of personalized medicine are still "in embryonic stages" (STPI, 2010, p. 2-4).

    Another example is the manufacturing of eye lenses with personalized features. Advances in manufacturing processes are enabling the automation of lens manufacturing for improved quality at a reduced cost (STPI, 2010).

    In the fashion industry, 3D imaging and scanning technology could be used in high-tech booths to provide customers with a virtual body image. This could then be used to identify clothing that would perfectly fit the customers' body shapes, or to quote one-off pieces of clothing (German Academy of Sciences, 2011).

    Although special needs are addressed in several standard bodies, there is no standardization process so far that addresses all the needs of customers of all ages. As a result, product designs do not usually take the specific requirements of seniors or people with disabilities into account. Given the fact that such consumers constitute minority groups, they would be excluded from the advantages of an economy of scale if the products were to be made exclusively for them. A more suitable approach would be the adoption of principles of design for all, wherever possible, to strive for adaptable designs in most cases and to offer assistive technology where necessary (European Commission, na.). Design for all refers to products which are made in such a way that they can be accessed and used by people with the widest range of abilities in a safe and convenient way. Adaptable design implies that a product can be adjusted to the needs of the individual user with the help of adjustment options or accessories. Assistive technology refers to technology used to construct new products specifically targeted at elderly people or people with disabilities to compensate for a decrease or loss of physical functions.

- *Competitively affordable customized production*. With constant changes in product volumes and mix, manufacturing firms will have to respond to a much wider range of product specifications in shorter time frames at an affordable price. This can be achieved through modularity, in which many diverse sub-assemblies can be configured in different ways to broaden the production line, offer a customized product for different market segments and reduce manufacturing costs. Modularity embodies flexibility and allows for affordable customization while combining the advantages of standardization—high volume and low manufacturing costs—with those of an individualized product.

E. Human-centred manufacturing

Manufacturing firms will need to account for changes in workforce demographics in order to secure the skills necessary for operating the factories of the future. They will also need to provide fulfilling jobs and safe working environments. Required qualities and characteristics for human-centred manufacturing identified in our review include:

- *Human focus*. In spite of all automation efforts, people still play a key role in the implementation, operation and general success of a manufacturing system. In fact, human operators can be considered the most flexible component of a manufacturing system. A strong emphasis is therefore needed on people's unique role as innovators and decision-makers in the manufacturing enterprise which will be developed and cultivated by better integrating humans with technology (Teknikföretagen Production Research, 2008).

- *User focus*. There is an emphasis on the need to understand why and how technology can support human work. Manufacturing systems will need to integrate user-interaction mechanisms. Additionally, improvements in the socio-economic dimension of future metropolitan areas and factories will be required by addressing the quality of life of citizens living and working there (EFFRA, 2011).

- *Demographically balanced factories*. Demographic change and its impact on manufacturing should be managed across several areas including age structure, share of female employees, migration and regional background, working conditions, ergonomics, preventive health-care and working hours. The most pressing issue seems to be ageing and the loss of tacit knowledge among older employees (EFFRA, 2011). This occurs when companies fail to take adequate measures to ensure the proper capture, transfer and reuse of knowledge of older employees. Some companies have not ensured a balance between old and new employees and keep positions vacant long after the older employees retire, only to fill them with young inexperienced staff. Workplaces will therefore need to provide opportunities for this employee overlap. A balanced age structure approach would allow manufacturing companies to achieve a "healthy" working atmosphere. Apart from the ethical aspect, it also fosters knowledge retention and offers a high potential for a successful innovation process, as many innovations are driven by older employees. Opening new opportunities for this age group may have a positive impact on the younger staff who could benefit from the experience and pragmatism of older practitioners, thus shortening their learning curve. On the other hand, a balanced working environment may rejuvenate the mindset and thinking of older employees. Finally, wage and employment systems will need to be adapted to local context, jobs should be created near urban agglomerations, and risk and safety management as well as production ergonomics should be implemented (EFFRA, 2011).

E.1. Organizational and technological solutions, concepts and innovations for enabling human-centred manufacturing

- *Consumer-oriented*. Many actors inside or outside an organization (including customers) influence a manufacturing company's operations. They are their direct or indirect partners. For example, the "Gläserne Fabrik" (Transparent Factory) for VW cars in Dresden established a new manufacturing culture, allowing customers to watch the assembly of the Phaeton automobile and thus be active participants in the production process. This was accomplished by replacing the walls inside the factory with glass and by making it visitor friendly with no smokestacks, loud noise or toxic products. This type of transparent factory offers not only optical transparency, but also, and most importantly, the transparency of the production process establishes a link between technology, environment and people.

- *Cooperation between robots and humans* must be improved without compromising safety. Other important areas of research are advanced user interfaces, mobile and "hidden" information technology, social networks for problem solving, production ergonomics and virtual representations of humans in production simulations. New technology is also needed as support for human decision-making in problem solving. Fast feedback on process experiences from operator to production and product developers are crucial factors.

- *Understanding the role of humans in production systems*. In spite of all automation efforts, people still play a key role in the implementation, operation and general success of a manufacturing system. In fact, human operators can be considered the most flexible component of a manufacturing system. A distinction can be made between the "user focus" and the "human-centred focus" of production systems regarding how technology is designed. The human-centred approach focuses on how humans interact with technology and places human skills, creativity and knowledge at the centre of a technological system. On the other hand, the "user focus" approach focuses on why and how technology can support human work. Therefore, a strong emphasis is placed on humans' unique role as innovators and decision-makers, which can be developed and cultivated by better integrating humans with technology and by enabling maximum synergy between people and technology (Teknikföretagen Production Research, 2008).
- *Networked multimodal collaboration in manufacturing environments* aims at enhancing the interface human-machine-human through new and innovative, easy and friendly modes of interaction (Jovane et al., 2009). The interface between human and machine must be user friendly and tailored to the individual's situation. User interfaces should reduce complexity for the operator, but simultaneously maintain the full extent of the system's control. Total system performance can be radically increased by smart integration of human "knowledge workers" into semi-automated manufacturing systems by means of dynamic and analytic task allocation, optimized levels of physical and cognitive automation, dynamic interaction between humans and technology and integrated competence development capacity (EFFRA, 2011). In the future, however, the traditional human-machine interaction will be replaced by human-robot cooperation which will increase flexibility and reduce manufacturing time to an even larger extent.

F. Sustainable manufacturing

Manufacturing does not only create pollutants, but is also energy intensive. It is estimated that industry accounts for about one-third of the total energy use in the United States, with manufacturing responsible for around 80 per cent of industrial use (STPI, 2010). Some of the qualities and characteristics required to achieve sustainable manufacturing identified in international exercises include:

- *Sustainability value-based enterprises*. Consumers' expectations and demands are changing in such a way that they relate to and will only purchase from companies that share values according to their own set of principles. Thus, a new type of 21st century company is emerging that is transforming how business is conducted (McKinsey, 2009). These are value-based companies that define a core set of values and rely on these values to make strategic decisions. From the environmental point of view, such companies engage in the production of goods and services with the least possible negative impact on the environment, and will search for new ways to minimize resource and energy consumption. This, for example, can be achieved through the reduction of the total carbon footprint, toxic substance removal, use of environmentally friendly materials, smaller packaging, product recyclability, energy efficiency, etc.

- *Efficient and effective manufacturing: affordability and sustainability*. Manufacturing companies are facing major challenges as environmental requirements entail radical changes in product design, production systems and the production process while increased competition from low-cost countries creates a strong urgency for lower prices and more affordable products. An important driver for the production of sustainable but affordable products will be the use of new technologies to improve productivity (yield), to ease materials recycling and reuse, and to increase the efficiency of manufacturing processes (EFFRA, 2011). The challenge for a manufacturing company is to promote sustainability along the supply chain. Sustainable supply and reduction of raw materials and energy use will be important issues. Material studies (technical and theoretical) and energy reviews, including life cycle costs, stable and controlled supply infrastructure and recycling, are needed to ensure the future sustainability of production systems (Geyer, Scapolo, Boden, Döry, & Ducatel, 2003). The development of sustainable unit processes may not only protect the environment, but also lower production costs (STPI, 2010).
- *Sustainable global value added*. The emergence of developing countries is shaped by the use of existing major technologies, which increases the global consumption of each ecologically, economically and socially acceptable limit. A combination of partly radical innovations in product, process and consumer behaviour is necessary to overcome the resulting dilemmas (German Academy of Sciences, 2011).

F.1. Organizational and technological solutions, concepts and innovations for enabling sustainable manufacturing

- *Evolution from cradle-to-grave economy to cradle-to-cradle economy*. Although the cradle-to-grave system allowed for technological development which improved the lives of many, its negative consequences such as pollution, resource depletion and degradation, and the production of toxic and harmful materials have become more apparent and have serious consequences for the environment and day-to-day life. Although some of the approaches employed today such as recycling and emissions reduction tend to lower the negative impact to some extent, they are not as effective at reducing the harmful activities themselves. Recycling electronic appliances, for example, might reduce consumption, but if the products contain hazardous materials, the recycled product ends up in a landfill, where it becomes hazardous waste. The cradle-to-cradle industrial system, on the other hand, is a concept that aims at regenerating the cycles of nature by providing eco-safe and cost efficient systems. Such systems are based on designs that can purify air, water, land, do not generate toxic waste, use healthy, non-harmful materials that can be continuously recycled, create positive emissions and generate value for all stakeholders. For example, some companies[4] have developed technical nutrient carpet tiles designed to be used as raw materials for similar products after disposal in order to ensure that no waste is generated.

- *Resource-efficiency from the life cycle and value chain perspective*. Reducing the total environmental impact of the production and consumption of goods and services requires a holistic perspective that takes the range of activities into account, from raw material extraction to final use and disposal (UNEP, 2009). Therefore it is important to assess how resources are extracted, processed, consumed and disposed along the value chain. Environmental problems are often complex, and hence solutions and environmental trade-offs are complex as well. For example, next generation lightweight composites tackle the fuel efficiency problem but at the same time create others. Composite materials increase waste because they are currently not recyclable and no feasible recycling technologies are on the horizon, either. Firms are likely to ignore the cost of environmental remediation of their activities (STPI, 2010).
- *Lean green manufacturing*. Another driver will be the adoption of "lean green manufacturing". This approach aligns with lean concepts to reduce work-in-process costs, increase productivity and quality as well as profits through the reduction of total energy use, waste sent to landfills, greenhouse gas emissions and water consumption, among other negative environmental impacts (Yakimov & Woosley, 2010).
- *Energy-efficient factories*. Some initiatives have been taken to ensure energy efficiency in modern establishments. For example, Farmacias Ahumada's distribution centre is the first bioclimatic project in Chile. The air conditioning system uses geothermic technology for different parts of the building, wind and solar power, and natural zenithal lighting. Intel's Fab 32 semiconductor manufacturing plant uses natural skylights, solar energy, retention ponds and reflective roofing. Equipment control is also optimized for energy savings—thanks to the "sleep" mode—and a focus on recycling water and chemicals to reduce waste has led to a 15 per cent reduction in greenhouse gas emissions and conservation of 70 per cent of the water used.

G. Innovation-receptive manufacturing

The competitiveness of future manufacturing firms will be increasingly linked to their ability to rapidly transfer developments in S&T into their processes and products. Technological and operational upgrading will require the adoption of innovations developed both in house or elsewhere in the world. International studies point out a number of requirements for innovation-receptive manufacturing, including:

[4] http://www.shawcontractgroup.com/Html/EnvironmentalCorporateSustainability

- *Open innovation manufacturing*. Initially, large manufacturing firms have solely relied on their internal expertise to manage the entire R&D process in order to be first in the market. However, this led to huge overheads, and as global markets became more competitive and time and cost sensitive, companies shifted their focus to a more open approach in which they cooperate and rely to a higher degree on external resources for innovation. Open innovation is a process designed to accelerate innovation by allowing companies to share and integrate resources with partner organizations and internal business units (IfM, 2009). It involves companies becoming less reliant on internal ideas and being prepared to work with other firms to facilitate innovation and produce new products faster and with higher efficiency. The most important reasons for adopting open innovation include: *(a)* shorter time to market; *(b)* acquiring new technologies and ideas; *(c)* access to additional expertise; *(d)* cost savings, and *(e)* access to new markets (IfM, 2009). There are also strong indications that more and more United States firms are voluntarily sharing their research, development, design and patent information. Recent data from the National Science Board reveals that United States companies conducted over US$ 6 billion in trade with unaffiliated companies in receipts and payments in 2005. This includes United States trade in industrial processes, including patents and trade secrets, used in the production of goods (Yakimov & Woosley, 2010).

  The likelihood of success of innovative products is based on the cooperation along the supply chain networks in which participants are able to match their technological knowledge with complementary expertise from other areas. To achieve systemic innovation, firms will need to go further and coordinate with producers of complementary products and in many cases even with direct competitors to ensure the viability of their innovations rather than coordinating with suppliers and customers only, as is frequently the case in closed innovation models (Maula, Keil, & Salmenkaita, 2005).

- *Facilitating user-centred innovation*. Customer-driven product development is a paradigm that places the user of a certain product at the heart of the innovation process. One of the main requirements is that users must be involved in the product development process of the product they will use, thus enabling customer-designer-manufacturer interaction. The methods and processes associated with user-centred design are derived from multiple disciplines including, among others, human factors, ergonomics, psychology, ethnographic studies and document design (Sugar & Boling, 1995). Firms can profit from innovations developed by users because innovating users tend to be ahead of the market, i.e. they are "lead users". Moreover, lead users often form communities and freely share their innovations with manufacturers (Lettl, na). According to (Lilien, Morrison, Searls, Sonnack, & von Hippel, 2002), lead user-based products produce eight times more revenue than products based on in-house ideas

- *Preparing for social innovation*. The size and global spread of manufacturing companies have grown in the last decade, as has the approach on the social focus of these companies. Companies are turning to a shared value model, slowly shifting from the typical financial donations to a more active role such as using corporate assets and employee skills to drive social change. Social entrepreneurship is a newly emerging concept and refers to strategies, concepts or ideas that enable organizations to develop an innovative solution to a social problem. The main difference between social innovation and business innovation is that business innovations are generally motivated by profit maximization while social innovations produce mutual benefits for corporations and, most importantly, for society as well. For example, HP has employed its technology expertise to develop a service that helps detect counterfeited medicines in Africa.

G.1. Organizational and technological solutions, concepts and innovations for enabling innovation-receptive manufacturing

- *Reactive information systems*. To be effective, manufacturing information systems must be capable of capturing data from multiple sources and to transmit these across the system in usable formats. If properly implemented, such a system can match customer demands with supplier availability and production capacity and deliver the product on schedule by providing information on precisely what is needed, when it is needed (STPI, 2010).
- *Learning factories*. Organizational learning is a well-known methodology for industry. It leverages individual learning (skill, experiences), learning as a methodology for permanent improvement of processes or learning by benchmarking. Learning organizations have been implemented in many enterprises as part of the management system. Learning is a process to reduce losses or improve productivity by analysing past operations, using experience, creating new solutions and activating explicit or implicit knowledge. Learning factories are characterized by the implementation of learning systems in technical solutions, self-adaptation, cognitive IT, pro-active improvement and integration in the holistic production system. To activate the full future potential of learning factories, some new areas are of significance for all manufacturing sectors.
- *Digital libraries*. Digital library services are considered a key component of factory digital infrastructures, allowing content and knowledge to be produced, stored, managed, personalized, transmitted, preserved and used reliably, efficiently, at low costs and according to widely accepted rules, standards and protocols. Several scientific goals are envisioned:

    Ensuring long-term accessibility and usability of the digital factory's content, namely parts and components which have to be available in digital form through digital libraries;

    Developing new and more effective technologies for intelligent content creation and management, and supporting the capture of knowledge, its sharing and reuse;

    Developing new methods for supporting people and organizations to identify new ways of acquiring and exploiting knowledge, and thereby to learn.

- *Manufacturing the products of tomorrow*. To stay competitive, manufacturing companies need to deliver products that satisfy customers' unmet needs that have the potential to open new markets. Enabling technologies such as photonics, micro and nanoelectronics, industrial biotechnology, nanotechnology and advanced materials will support the introduction of such future products in the next years and decades. In addition, societal challenges such as energy constraints, health and an ageing society stimulate the emergence of new products (EFFRA, 2011).

IV. Emerging science and engineering developments

This chapter provides insights into science and engineering developments emerging out of the research and innovation base, which are expected to gain relevance in industrial systems in the future. They are likely to play an increasingly prominent role in enabling the production-related solutions and concepts described in the previous chapter.

National and regional research strategies (such as 10-year plans) and technology reviews (including prospective studies), in particular, have been major sources of information for this chapter. They have most commonly been set out to identify national future research priorities in science and engineering and are therefore concerned with technology and manufacturing advances that will potentially be critical in the short and long term. Countries and regions in the review include the European Union, Germany, United Kingdom, Denmark, Sweden, China, United States, Canada, Australia, Republic of Korea and Brazil.

Different types of stakeholders have participated in the preparation of the documents included in our review, ranging from research institutes and academic experts to government agencies and industry representatives. Therefore, a diversity of emphases, approaches and topics are covered. Academic experts, for example, tend to focus on basic research needs while industrialists tend to place more emphasis on technology applications for the creation of competitive advantage vis-à-vis competitor countries.

The listing of scientific and engineering developments presented in this chapter is by no means comprehensive. Nevertheless, this chapter identifies trends emerging internationally. Notably, considerable emphasis was found on "enabling" or "platform" technologies. These refer to those technologies expected to underpin future manufacturing capabilities in a broad range of manufacturing industries, enabling the next wave of high value products and production technologies. Their influence is pervasive, providing the basis for the development of new industries and business models in the future, and with the potential of inducing structural change (High Level Group on Key Enabling Technologies, 2011).

Additionally, driven by growing environmental concerns and the related need for resource efficiency in manufacturing, some international studies specifically discuss emerging engineering and scientific developments relevant for new or improved environment and energy technologies.

Specifically, the following technology areas are emphasized.

- *Photonics*. Including scanning, sensing and imaging; information, communication and networks; screens and displays; advanced lighting; photonic energy systems; and laser systems.

- *Biotechnology*. Including biopharma; tissue engineering/regenerative medicine; synthetic biology; and bio-inspired manufacturing using self-assembly.
- *Nanotechnology*. Including carbon nanotubes; nanocomposite structural materials; nanoelectronics; nanotechnology-based coatings; nanoparticles; and nano-tagging.
- *Microtechnology*. Including microtooling (for replication) manufacturing and micro-systems in machine tools and products.
- *Information and communication technology (ICT) in manufacturing systems.* Including intelligent mechatronic systems for automation and robotics (e.g. self-adapting components) and advancement of grid computing for manufacturing.
- *Advanced materials*. Including advanced composites and "metamaterials".

These technology areas are highly multidisciplinary and trans-sectoral, their development being driven by breakthroughs in physics, chemistry, materials science and biology as well as the convergence of these disciplines. They are associated with high knowledge intensity, high R&D costs, rapid innovation cycles, high capital expenditure and highly-skilled employment (DG Enterprise and Industry, 2010). They are of systemic relevance, multidisciplinary and trans-sectoral, cutting across many technology areas with a trend towards convergence (High Level Group on Key Enabling Technologies, 2010). Their impact is expected to differ across the range of established industries.

A recent international study conducted by the Institute for Defense Analyses for the United States Office of the Director of National Intelligence (IDA, 2012) investigated national research investments in manufacturing-specific R&D. It finds that the largest public investments are in the fields of ICT and applications of nanotechnology. The study also found a significant focus on low-carbon technologies in Asia and green manufacturing processes in the European Union.

National priorities seem to reflect local historical industrial structures and/or strengths, as well as the interests of dominant manufacturing industries within the economy. Other examples of national variations in terms of emphasis include (O'Sullivan, 2011):

- United States emphasis on next generation materials (and novel materials engineering) for manufacturing.
- Japan's focus on the implications of demographic change: prioritization of research on new production technologies for an ageing workforce and opportunities associated with the manufacture of new products for an ageing population.
- Germany's efforts related to manufacturing processes that protect products from piracy.

- Japan's prioritization of visualization technologies and integration of other IT systems with production technologies to enhance the competitiveness of manufacturing systems.
- Brazil's emphasis on biofuel and petrochemical technologies.

A recurrent discussion presented in some of the studies analysed are currently at different stages of development (i.e. different technology readiness levels) and commercialization of emerging priority technologies. According to some estimates, the integration of new ICT solutions and micro electromechanical systems (MEMs) into manufacturing operations is expected in the short term. Advanced materials appear important in the short- to medium-term research agenda, and new manufacturing technology principles underpinned by nano- or biotechnologies are only expected to be realized in the longer term (IDA, 2012; ManVis, 2006).

A brief description of the areas of technology previously mentioned is provided in the remainder of this chapter. A detailed description of these technologies is beyond the scope of this report. However, the descriptions presented here provide insights into the expected nature of the change they can drive in manufacturing systems in the future.

A. Photonics

Photonics, also known as optoelectronics (OE), is "technology space where information signals carried by electrons are converted to photons and vice versa (O-E-O)" (STPI, 2010, p. 1-6). The application of photonics covers a diverse range of areas, including industrial lasers, consumer electronics, telecommunications, data storage, biotechnology, medicine, general illumination and defence. Photonics allows optical transmission of information, with the potential for development of new medical and lighting applications and alternative energy sources.

The development of integrated optoelectronics is driven by the growing needs of the telecommunications industry. Services such as new "smartphones" and Internet video content will increase users' bandwidth demand. As consumer demand grows and data traffic increases, telecommunication networks and data centres will require increased performance at reduced costs and lower power consumption. These centres typically contain "thousands of racks of electronic routers, in buildings that cover acres, and consume about 30 megawatts of electric power" (STPI, 2010, p. 1-6). Any increase in bandwidth capacity using traditional technologies implies an increase in power consumption and heat dissipation requirements. Integrated optoelectronics circuits, which combine multiple optic and electronic functions on a single chip, have the potential to overcome these physical restrictions.

B. Biotechnology

Biotechnology is one of the areas that has received the most attention in the international exercises included in our review. Thanks to advances in the science of genomics, manufacturers are already working with biomaterials, creating bio-products and using bioprocesses. Industrial biotechnology is likely to have an increasing impact on the food, chemicals, energy, pharmaceuticals and textiles industries, enabling these industries to manufacture products in an economically and environmentally sustainable way (DG Enterprise and Industry, 2010).

Biomanufacturing harnesses living systems "to produce desired products by purifying a natural biological source (e.g., penicillin from mold) or by genetically engineering an organism to produce a product" (IDA, 2012, p. 43). Biomanufacturing processes are complex, labour-intensive and expensive. Production is highly variable because it involves living organisms and biomanufacturing is therefore hampered by a lack of predictability and standardization. Production processes must be designed on a case-by-case basis and cannot be easily transferred from one company to another (IDA, 2012).

B.1. Biopharmaceuticals

Biopharmaceuticals is the most active area of the application of biotechnology, having increasingly shifted from the traditional metabolites, antibiotics, steroids and vitamins to newer biotech concepts including recombinant proteins, monoclonal antibodies and gene therapy. Many of the new products developed for application in the areas of oncology, neurology and inflammation are protein-based (Reynolds, 2010). Biopharmaceutical drugs mimic compounds found within the body and because of their specificity, they have the potential to cure diseases rather than simply treat symptoms, and have fewer side effects. Combined with the increasing number of new diseases treatable with biopharmaceuticals, these advantages are driving demand for this type of drugs worldwide. In 2008, biologics—drugs made through a biological process rather than chemical synthesis—represented 30 per cent of the revenue of the top-100 drugs and that percentage is expected to rise to 50 per cent by 2014 (Singer, 2011).

Biopharmaceutical manufacturing brings a high degree of uncertainty and is extremely risky and costly because unlike other goods-producing industries, such as the electronics or automotive industry, it involves direct interaction with the human body, our knowledge of which is still limited. On average, bringing a new drug to the market takes more than 10 years and costs over US$ 1 billion. More than halfway through the process, close to half of all drug candidates fail. While a patent is granted for 20 years, companies may spend half of that time developing a new drug, obtaining drug approvals and commercializing it. A new trend in biopharma manufacturing is the so-called "rare focus", the production of drugs for rare diseases, as biotech companies are targeting niche markets and unmet medical needs (Reynolds, 2010).

Challenges in global biopharmaceutical manufacturing in the future include the following (STPI, 2010):

- Optimizing expression systems: to reduce production variability
- Improving product and process characterization

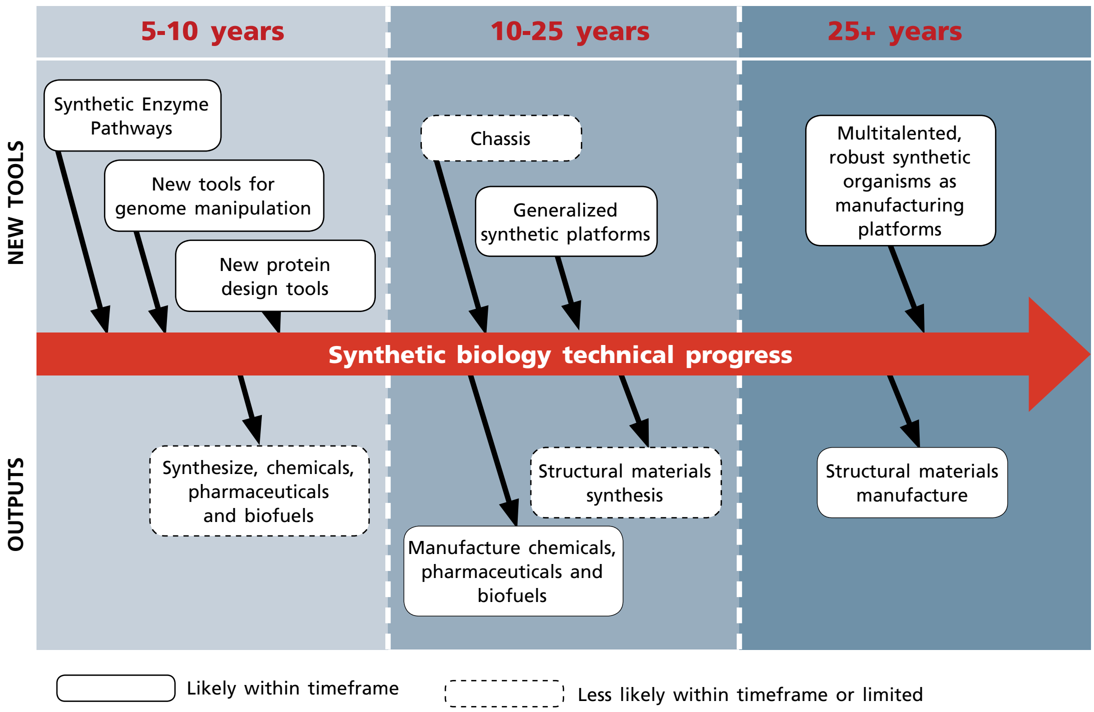
- Streamlining plant design and operations: capital investment for plants is large and has to be done based on demand predictions
- Stringent and changing regulatory environment requirements for process validation
- Workforce shortage.

B.2. Synthetic biology

Synthetic biology is a nascent area that aims to "design and engineer biologically based parts, novel devices and systems as well as redesigning existing, natural biological systems" (Royal Academy of Engineering, 2009, p. 6). Synthetic biology can also be understood as a field that "tries to build a large toolbox of biological techniques and technologies to truly understand biological systems" (IDA, 2012, I-11). The advancement of DNA sequencing and related understanding of gene and protein functions (including advances in genomics, proteomics, systems biology and genetic engineering) have made synthetic biology "ripe for exploration" (STPI, 2010, p. 1-11).

Synthetic biology has achieved some successes in biopharmaceutical development, and experts believe that tool development will be the most important development in synthetic biology in the next few years. The expected timeframe of these developments is illustrated in figure VII.

Figure VII. Potential advances in biomanufacturing with synthetic biology tools



Source: IDA, 2012.

Note: New methodologies and tool development are shown above the red progress arrow, and potential outputs below the arrow. Dotted lines around the tools and outputs indicate less confidence in achieving these goals within the timeframe.

Besides pharmaceuticals, synthetic biology could be an enabling technology for a range of industries including chemicals, biofuels (biodiesel and ethanol), sensors, agriculture, materials and computing (Royal Academy of Engineering, 2009).

It is believed that synthetic biology could change the manufacturing of biological products in 20 years (IDA, 2012). Its potential is assumed to be considerable, perhaps even more so than synthetic chemistry's in the 19th century (Royal Academy of Engineering, 2009). (Synthetic chemistry enabled the development of the pharmaceutical industry as well as much of the food industry, detergents and petrochemical industries). It is believed that synthetic biology has the potential to "transform world industry in areas such as energy, health and the environment; to produce a new era of wealth generation; and create large numbers of new jobs" (Royal Academy of Engineering, 2009, p. 9). However, synthetic biology is still an immature field that faces a number of technical and policy challenges—ethical, biosafety, biosecurity, societal and intellectual property—that need to be addressed if its potential is to be realized (IDA, 2012).

B.3. Tissue engineering

Recent developments have also been made in tissue engineering. The United States Multi-Agency Tissue Engineering Science (MATES) defines tissue engineering as "the use of physical, chemical, biological, and engineering processes to control and direct the aggregate behaviour of cells" (MATES, 2012). This is a field that overlaps with regenerative medicine, which is based on the use of stem cells. Tissue engineering primarily focuses on the creation of complex biological materials, including bones and organs (STPI, 2010).

Opportunities in these areas exist for the production of blood cells and products, the development of materials for the delivery of small molecule drugs and biologics, bioactive coatings and surgical materials (e.g. tissue sealants) (Future Manufacturing Council, 2011).

In the United States, substantial federal R&D funding has been given to tissue engineering (STPI, 2010). However, this is a developing area that still requires more basic research. While several tissue engineering companies already exist, they have not yet been able to achieve large-scale revenues (STPI, 2010). Similarly, the cell therapies market is estimated to reach US$ 2.3 billion by 2025, but regenerative medicine "will still require a new generation of instructive, advanced materials able to coordinate local cellular processes or to act as materials for the in vitro production of stem cells for the 'cell therapies' treatment of human disease" (Future Manufacturing Council, 2011, p. 32).

C. Nanotechnology

Nanotechnology is another area that is mentioned in practically every technology-related document included in our review. Nanotechnology involves the "construction and use of functional structures designed from atomic or molecular scale with at least one characteristic dimension measured in nanometers" (Wang, 2004, p. 56). At the nanometer scale, these structures display novel and improved physical, chemical and biological properties, phenomena and processes.

New applications of nanotechnology are expected to revolutionize manufacturing activity and significant investments are being made in this field, both in the private and in the public sectors in countries around the world. This is because nanotechnology could impact the production of virtually every manufactured good—from automobiles and electronics to advanced diagnostics, surgery, advanced medicines and tissue and bone replacements (SRI, 2004). According to some estimations, total worldwide sales for nanotechnology amounted to US$ 11 billion in 2009, a figure that is expected to increase to US$ 26 billion by 2015. Countless new nanomaterials have been developed in laboratories worldwide with as many potential applications. Recent patent analysis suggests that nanotechnologies will be particularly important for chemicals, pharmaceuticals, metals, engineering and electronics (DG Enterprise and Industry, 2010).

Nevertheless, the realization of "real world products" based on nanotechnology has faced many obstacles. According to the High-Level Group established by the European Commission to study "key enabling technologies[5]", the road from scientific discovery to commercial application has been particularly long and complicated for nanomaterials. They found that all too often, new exciting materials "never leave the laboratory stage" (High Level Group on Key Enabling Technologies, 2010, p. 25). To overcome this problem in the future, the Group suggests that academia, materials producers and final system integrators along the entire value chain will have to work in close collaboration. They also emphasize the need to simultaneously involve key stages of the value chain in the innovation process rather than the traditional linear approach in which most attention is given to the providers of the final consumer product (which are often mistakenly perceived as the leaders and only innovators of the value chain).

Nanoscale manufacturing is multidisciplinary, involving—but not limited to—mechanics, electrical engineering, physics, chemistry, biology and biomedical engineering. Conventional technologies for the production of nanomaterials include (High Level Group on Key Enabling Technologies, 2010):

- Synthesis
- Novel gas phase processes (e.g. plasma- or microwave-assisted processes)
- Novel wet processes (e.g. sol-gel processes)
- Dispersion and stabilization

[5] This working group built on national technology reviews in Europe, notably in Germany, France and the United Kingdom.

- In-situ functionalization and formulation
- Integration in patterned and final systems.

In the future, the development of new nanomaterials will require the combination of new and existing process steps. Advanced manufacturing technologies include (High Level Group on Key Enabling Technologies, 2010):

- Self-assembly
- Self-organization (with long range order)
- In-situ generation of nanostructured materials
- Scale-up by transferring patterning techniques from small-scale lab processes to reel-to-reel manufacturing technologies.

Our review suggests that there is a certain degree of consensus that the integration of engineering, science and biology will drive advances in nanomanufacturing in the future. A key challenge will be achieving not only affordable commercial scale production, but the integration of nanomaterials into traditional manufacturing processes (STPI, 2010). New knowledge, tools and approaches to scientific enquiry and production systems will also be necessary. Similarly, the development of multidisciplinary skills in manufacturing firms is also deemed crucial for achieving the potentials of this technology area.

D. Additive manufacturing

Additive manufacturing (AM) encompasses multiple techniques used to build solid parts by adding material in layers (IDA, 2012). AM applications have taken advantage of the capabilities of rapid prototyping (RP) technologies to produced parts with customized geometries (SRI, 2004). AM has been in use since the mid-1980s. It is still a small industry, with sales of systems, materials and services estimated at US$ 1.2 billion in 2010. From 1989 to 2010, the average compound growth rate was over 26 per cent (IDA, 2012).

AM techniques have been described by different terms with slightly different meanings, including *(a)* automated fabrication; *(b)* solid free-form fabrication; *(c)* direct digital manufacturing; *(d)* stereolithography; *(e)* three-dimensional or 3D printing, and *(f)* rapid prototyping. However, the term "additive manufacturing" has been adopted as the standard terminology to refer to the entire field (Gibson, Rosen, & Stucker, 2010). Figure VIII presents a description of selected additive manufacturing processes (note that the common future in all additive manufacturing approaches is the use of a layering approach).

Additive manufacturing stands in contrast to typical manufacturing processes in which material is removed or formed. Some of the benefits of AM vis-à-vis other technologies are as follows (IDA, 2012; SRI, 2004; STPI, 2010):

- AM reduces waste because it only requires the amount of material needed for producing a part or component.

- AM permits new types of design (including complex, 3-dimensional parts) without the imposed limitations of traditional machining.
- AM does not require investment of time and money into olds, fixtures, masks or other fixed tooling.
- AM reduces the need for large inventories because parts can be produced just-in-time or nearly just-in-time.
- AM allows distributed manufacturing concepts, since the components need not be produced in a factory.

Early application areas of additive manufacturing include consumer products, medical implants and tools, dental implants and aerospace. The United States and Europe are the current industry leaders (IDA, 2012). AM is being applied to fields such as tissue engineering and nanotechnology. American companies have recently built the first commercial bioprinter to produce human tissues and organs (STPI, 2010).

It is expected that future advancements in technology will lead to significant price reductions that will, in turn, drive further adoptions by both businesses and end-consumers. Some anticipated developments in the near to mid-terms include:

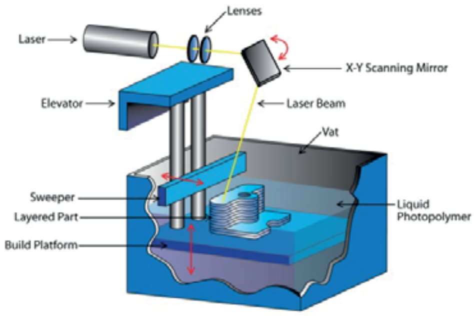
- The expectation is that by 2030, machines will have improved to the point that they can directly compete with traditional manufacturing technologies. In order to do so, it is anticipated that AM techniques will be capable of assembling products by area or by volume rather than by layering materials as is the case today, creating multiple material products quickly and at relatively high precision (IDA, 2012).

- When fully developed and scalable, AM will lead to economies of scale, thus making mass customization and easy changes in design possible (IDA,2012).

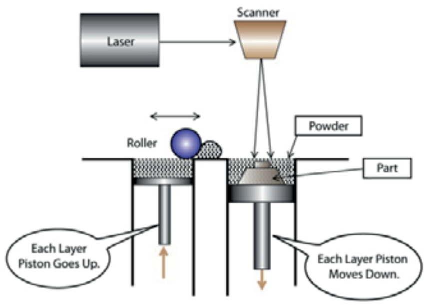
- Perhaps the “largest change in 20 years for additive technology” will be in biofabrication (IDA, 2012, p. H-17). Three-dimensional cancer models and drug-testing models may replace current animal models almost altogether. “At least the beginnings of regenerative medicine—fabricating functional tissues and organs to repair damage—will be possible in 20 years, if not the entire concept of living organ printing” (IDA, 2012, H-17).

- Patents for many of the established additive technologies will expire over the next 5 to 10 years. China, which is heavily investing in this technology, will almost certainly become a key player in several market segments as patents expire (IDA, 2012).

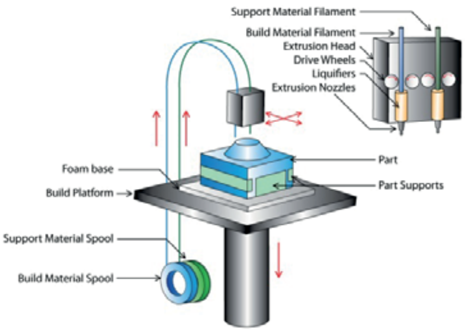
Figure VIII. Selected additive manufacturing processes



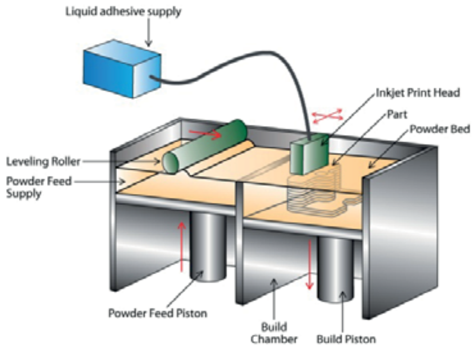
Stereolithography—This process makes use of photo-curable plastic resins that are treated by UV laser to become solid or gel-like and is most often used for prototyping (Hopkinson 2010).



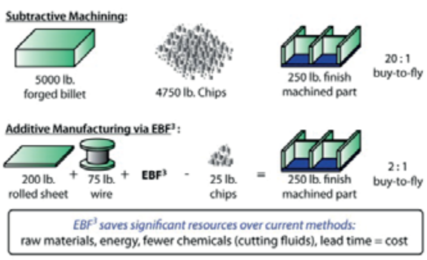
Powder bed (laser) sintering—Laser sintering fuses together powder from a bed. Originally, laser sintering could produce polymer as well as metallic and ceramic parts (using each type of powder), with binders needed in the case of metal or ceramic powders. Recently, more powerful lasers have been used to directly sinter metal and ceramic without the use of binders (Hopkinson 2010).



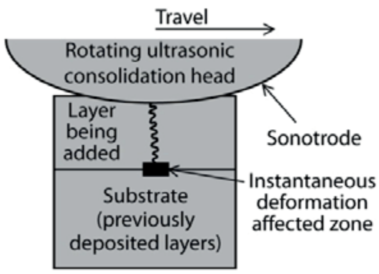
Fused deposition modeling (FDM)—This process uses hot nozzles to extrude polymeric material into position, using one nozzle to extrude support material and a second to extrude the part.



Inkjet Deposition (3D Printing)—This process uses an inkjet similar to those found in 2D printers. It works by depositing a binder on a powder bed that joins the powder in each layer without the use of lasers.



Electron beam melting or e-beam melting (EBM)—This is a process that uses an electron beam in place of a laser to directly melt metal powder into parts. (Arcam, a Swedish manufacturer, has pioneered the use of electron beam melting (Taminger 2008).)



Ultrasonic consolidation (UC)— One of the newest additive manufacturing technologies, patented by an American company called Solidica and in development by Solidica and the Edison Welding Institute (Slattery 2011). This process uses metal foils held together under pressure, combined with ultrasonic vibrations that create a weld between layers of foil, which are then machined to the desired shape (Domack and Baughman 2005).

Source: IDA, 2012.

E. Microtechnology

Microsystems, particularly Micro Electronic Mechanical Systems (MEMS), such as actuators and integrated sensors and microprocessors, are expected to be used across production systems in the midterm to make machines more intelligent and efficient (van der Zee & Brandes, 2007). While microtechnology is not a basic research topic, our review reveals that it has been prioritized because it is a technology that has further potential in the future.

Microelectronics is already a well-established industry, with applications in semiconductors, electronics, telecommunications, automobiles, aerospace and engineering (DG Enterprise and Industry, 2010). Micromachining (machining techniques that exist for the production of devices and mechanical parts at the micron scale) will enable greater precision, sensitivity and flexibility in micro-production processes (CME, 2005). This will allow using manufacturing machines more flexibly and will hence enable firms to tailor to individual customers' demands (ManVis, 2006).

One issue identified as a potential obstacle for the future adoption of micro-technology is the lack of regulations and standards. For example, MEMs tend to be specialized and customized products. While hundreds of standards exist for integrated circuits, almost none exist for MEMs. Lack of standards can keep costs for new applications high, which can hurt competitiveness in the future (STPI, 2010).

F. Information and communication technology in manufacturing systems

Information and communication technology (ICT) is already being widely used in modern manufacturing systems. However, some studies included in our review anticipate that new ICT applications will continue to revolutionize manufacturing activity, particularly in the short term.

ICTs will allow for productivity increases through automation (and associated technologies in controls and sensors) as well as through the reorganization of business processes (van der Zee & Brandes, 2007). Similarly, new machine interfaces are expected to enable further productivity increases.

ICTs will also be increasingly important in enabling new forms of communication between producers and costumers, thus providing the basis for customized manufacturing. ICTs are expected to enable new business models. For example, they will be crucial in the development of higher value-added product-services systems (ManuFuture, 2006).

Some of the ICT-related solutions that are expected to drive change in the operation and organization of future manufacturing systems include (EFFRA, 2011):

- Control technologies
  - Model-based development of machine control software
  - Learning controllers
  - Control methods that allow the adaptation of both feedback and feed forward control signals to changing environments
  - Optimal control techniques (taking into account constraints and considering alternatives)
  - Real-time communication technologies
- Advanced visual and physical human-machine interfaces
- Navigation and perception technologies
  - Visual capabilities (from macro to micro)
  - Navigation technologies
- Monitoring and diagnostics
  - Advanced signal processing or virtual sensing
  - Model-based, signal-based, data mining-based methods for a wide range of condition monitoring applications, e.g. event pattern detection, diagnostics, anomaly detection, prognostics and predictive maintenance
- Advanced structural system architectures
  - Reconfigurable machine architectures
- Actuator technologies/end effectors/locomotion
  - Gripper systems for complex part manipulation or assembly
- Energy technologies
  - Energy storage components, such as (super)capacitors, pneumatic storage, batteries, etc.
  - Energy harvesting technologies
- Integrated product-process-production system design and simulation techniques.

G. Advanced materials

Manufacturing industries are expected to increasingly make use of new materials to take advantage of improved characteristics, including increased functionality, lower weight, increased energy efficiency, etc. Advanced materials could enable new possibilities, not only in the form of novel manufactured products, but also in improved production processes and operations.

There are some overlaps between this category and the technology areas previously described, as some advanced materials incorporate technologies such as nano- and biotechnologies. A selection of advanced materials that are expected to gain relevance for manufacturing in the future include (High Level Group on Key Enabling Technologies, 2010):

- *Advanced metals*. Including advanced stainless steel, super-alloys and intermetallics.
- *Advanced polymers*. Including synthetic engineering non-conducting polymers, engineered plastics, conducting polymers or organic-electronic materials OPEs, advanced coatings, and advanced/nanofibres.
- *Advanced ceramics and superconductors*. Including nanoceramics, piezoelectric ceramics and nanocrystals.
- *Novel composites*. Including polymer composites, continuous fibre ceramic composites, metal matrix composites, nanocomposites, nanopowders, metal fullerenes and nanotubes,
- *Advanced biomaterials*. Including bioengineered materials, biosynthetics, nanofibres and catalysts.

A challenge for the future advancement of advanced materials is the development of robust, large-scale, fully integrated and flexible manufacturing methods (Fraunhofer IPA, 2007). While applications of advanced materials are expected across the range of manufacturing sectors, emphasis is being placed on their contribution in industries at the frontier of technological development. For example, Rolls Royce expects that if composite materials achieve their full potential, the gas turbine engine will have a significantly higher composite than today's: polymer matrix composites (PMCs) could constitute much of the nacelle, fan system, shaft support structures, casings and some stators; metal matrix composites (MMCs) will be used in the intermediate and high pressure compressor rotors; and ceramic matrix composites (CMCs) can be increasingly incorporated into the combustor can, nozzles and some of the rear structure (Rolls Royce, 2012).

H. Environmental and energy technologies

Manufacturing systems will require new materials, methods, processes and technologies to address the environmental challenges of the future. Since manufacturing firms produce technologies and equipment that are used by other energy intensive sectors, they have a cascading impact on the national and global use of resources. Our review reveals an emphasis on the promotion of these technologies in a number of manufacturing countries. Examples of clean energy technology include (EFFRA, 2011):

- Resource recovery and reuse
- Renewable feedstocks
- Electricity storage
- Fuel cells

- Renewable energy (solar, wind, geothermal, bioenergy, hydro)
- Nuclear fission and fusion
- Advanced vehicles.

Some of the above technologies require the application of other advanced technology areas previously described in this chapter. For example, one application of biotechnology will be the development of new high-performance catalysts, which should contribute towards the achievement of zero-waste emissions and the selective use of energy in chemical reactions. They will also enable the utilization of new and/or renewable raw materials and reuse of waste, and the solution to global issues such as greenhouse gas emissions, water and air quality (STPI, 2010).

V. Potential challenges and opportunities for manufacturing

A. Technological gaps

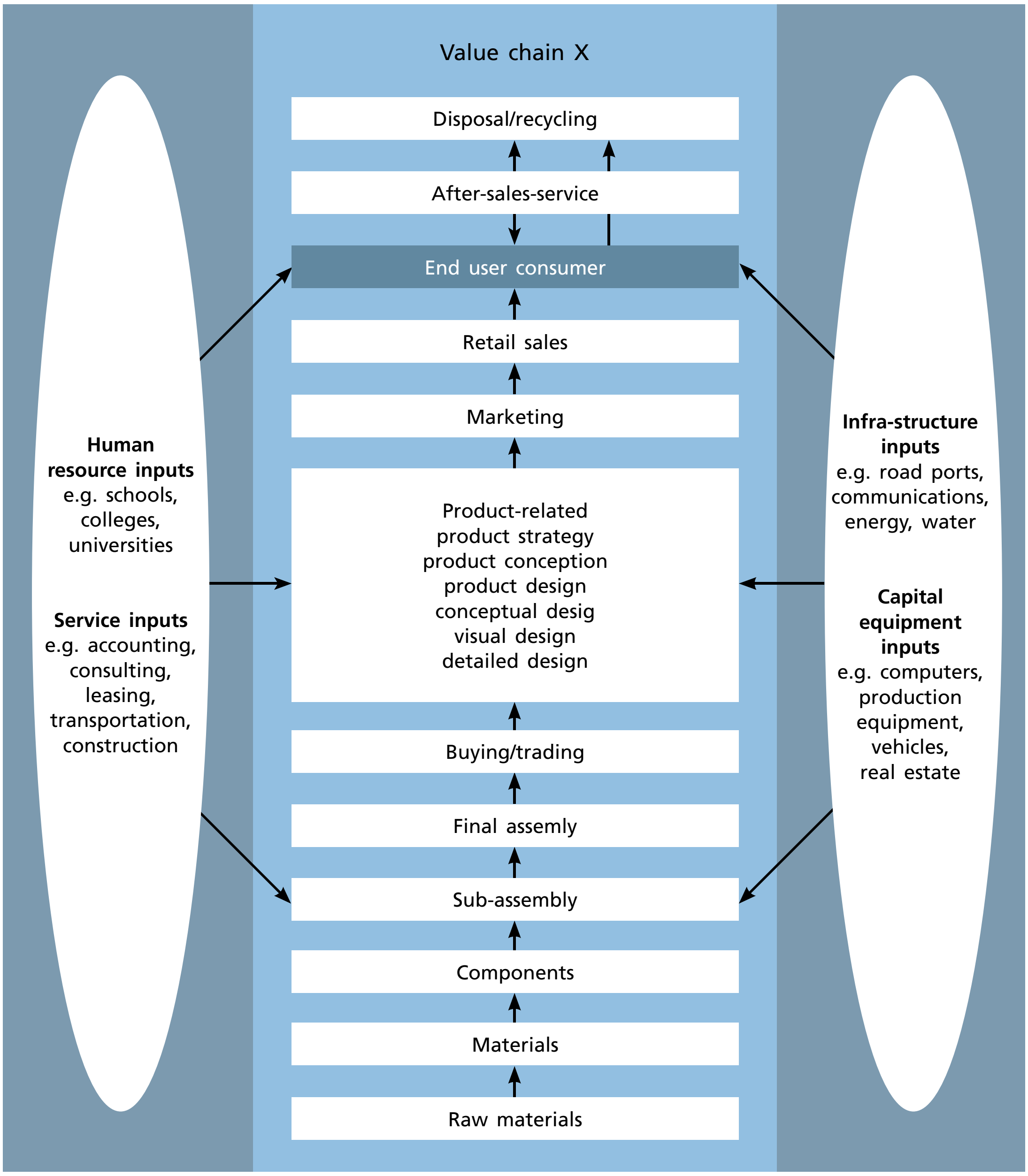
The identification of challenges and opportunities in national manufacturing industries is not a simple task. We first discuss some of the features of modern national industrial systems. We argue that technological gaps can be found in each of these elements and more detailed industry-specific studies at the regional and country levels are therefore necessary. We further argue that without conceptual frameworks that can account for the diverse elements of manufacturing systems, it will not be possible to fully understand how economies might enhance manufacturing competitiveness, address technological gaps and devise strategies for capturing value from modern value chains.

There is growing recognition across the countries included in our review of the profound transformations that manufacturing activities have undergone over the last decades in terms of structure, technology, sectoral inter-linkages and geographical boundaries. There is growing acceptance that such changes have increased the need to recognize the systems nature of manufacturing. As Sturgeon (2001) explains, modern value chains and production networks do not exist in a vacuum, but within a "complex matrix of institutions and supporting industries" (figure IX). At the most basic level, value chains are supported by a variety of critical inputs, including human resources, infrastructure, capital equipment and services (Sturgeon, 2001). Thus, the identification of technological gaps is necessary for approaches that go beyond traditional sectoral boundaries.

A.1. The systems nature of manufacturing

Manufacturing is increasingly understood as a system with 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. According to the United States Department of Commerce (2005), for example, manufacturing is now perceived as a system that is designed to carry out the necessary activities to deliver end-products to customers and satisfy their demands, ranging from design to finance, production to sales, marketing, and after-sales service.

Figure IX. The extended value chain with inputs



Source: Sturgeon, 2001.

In his influential article "Rationales and mechanisms for revitalizing United Sates manufacturing R&D strategies" (Tassey, 2010), Gregory Tassey asserts that the dynamics of comparative advantage between economies cannot be fully revealed by simply analysing individual technologies or particular industry sectors.6 He argues that not only are many of the most important modern

[6] Tassey's article appeared in the Journal of Technology Transfer, volume 35, No. 3 (2010) and is cited in the Obama Administration's "National Strategic Plan for Advanced Manufacturing" and related recent policy documents.

products themselves systems, but their manufacture relies on a range of industries contributing and integrating components, application subsystems, production systems, service systems, etc. According to this line of thinking, industry competitiveness depends on the effectiveness of networks among domestic firms.

To address the complexity associated with modern manufacturing, it is necessary to distinguish between different categories of manufacturing system elements and subsystems, some of which are summarized in figure X.

In Europe, manufacturing foresight-related exercises are part of the manufuture initiative which emphasizes the distinction between the industrial value chains of (commodity-based) "consumer industries" and those of (capital equipment-based) "factory supplier" sectors (Jovane et al., 2009). Specifically, it has been recognized that many of the production system innovations necessary for future competitiveness (and economic value capture) are likely to derive from production technology firms providing technological, system or process solutions in response to the needs of "consumer industries" (Eoin O'Sullivan & Mitchell, 2012).

Similarly, a number of high profile exercises have recognized the distinction between user industries (producers of consumer goods) and the suppliers of factories (producers of capital equipment goods) described below:

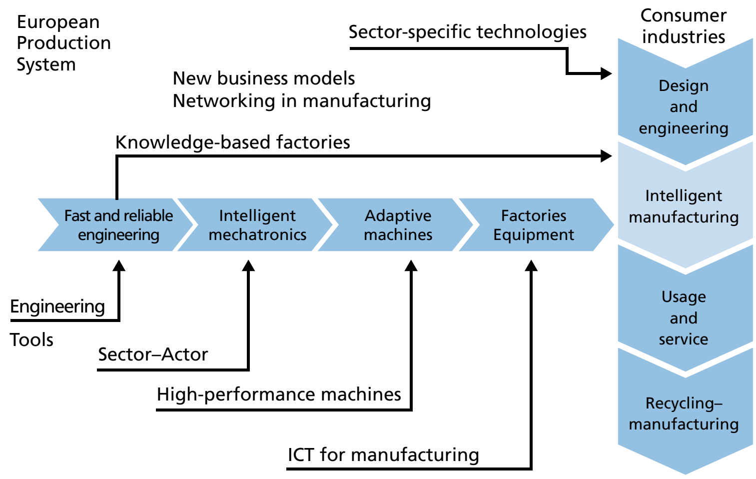
- *Suppliers for factories:* Manufacturers of capital intensive goods and services, who produce and deliver materials, component machines, systems and equipment for manufacturing: machine tools; prototyping tools; robotics, assembling and handling technology; measurement and testing equipment; packaging machinery; drive technology; pumping technology, etc.

- *User industries:* Manufacturers who produce products for consumer markets: aerospace; automotive; chemicals; pharmaceuticals; metal products (including automotive suppliers); power generation; medical technologies and devices, etc.

The "enterprise functions" within manufacturing enterprises represent another element of the manufacturing system highlighted in some of the exercises reviewed. Each manufacturing-related enterprise function may be influenced in different ways by the trends and drivers affecting manufacturing and some studies have therefore analysed them separately. For example, the German study Produktionsforschung 2020 (Abele, 2010) explores the impact of identified 'mega-trends' on manufacturing enterprise functions illustrated in figure X.

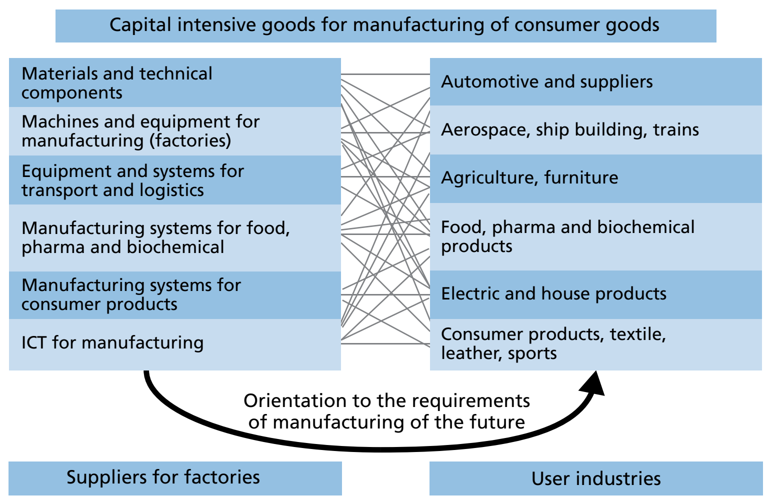
Figure X. Manufacturing system elements (and Subsystems)

Different types of value chains, in particular, industrial value chains of (commodity-based) "consumer industries" and those of (capital equipment-based) "factory supplier" industries



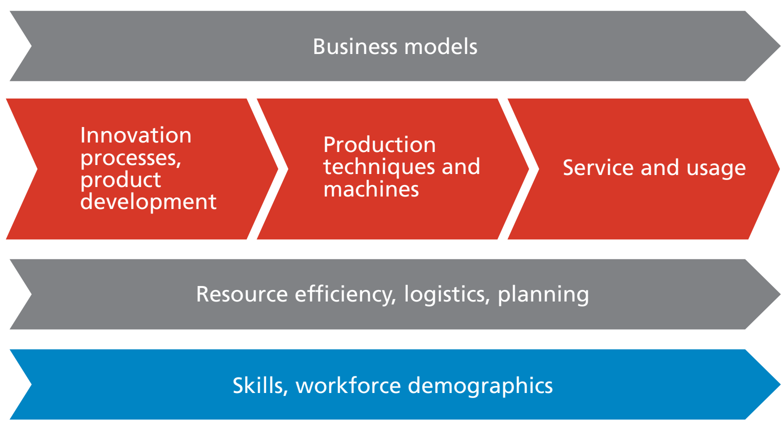
Source: Jovane et al., 2009.

Specialization of different types of manufacturing firms, in particular, factory equipment makers (capital goods) and factory users (consumer goods)



Source: Jovane et al., 2009.

Diversity of 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



Source: Abele, 2010.

A.2. Identifying technological gaps: the need for “deep dives”

Some countries’ long-term industrial competitiveness may depend on their ability to build and upgrade production-related capabilities and address technological gaps in specific industries. Such technological gaps are found not only in industrial value chains of (commodity-based) “consumer industries”, but also in those of (capital equipment-based) “factory suppliers”. While they are to some extent interrelated, we observe a growing recognition of the strategic importance of the latter.

As already mentioned, the crucial role for future competitiveness of production technology firms providing technological, system or process solutions in response to the needs of “consumer industries” is increasingly being recognized. In particular, many exercises highlight the linkages of such firms with other elements of the manufacturing system, which are considered part of the so-called “industrial commons”.[7] This term refers to a foundation of manufacturing-related know-how, competencies and capabilities (technical, design and operational) that are shared within a country’s or a region’s manufacturing firms, including: R&D know-how, advanced process development and engineering skills, and manufacturing competencies related to a specific technology.

This report argues that, as a first step, more detailed studies of the prospects of particular industries at the regional and national levels are needed, addressing the different manufacturing system elements and subsystems described above (different types of value chains, different types of firms, different types of enterprise functions, industrial commons, technological linkages, etc.). These “deep dives” in specific industries may provide insights into potential threats, opportunities, uncertainties and weaknesses associated with the future of manufacturing. Without such forward-looking analyses, particularly as inputs for industrial policymaking, many countries run the risk of “moving in the dark”.

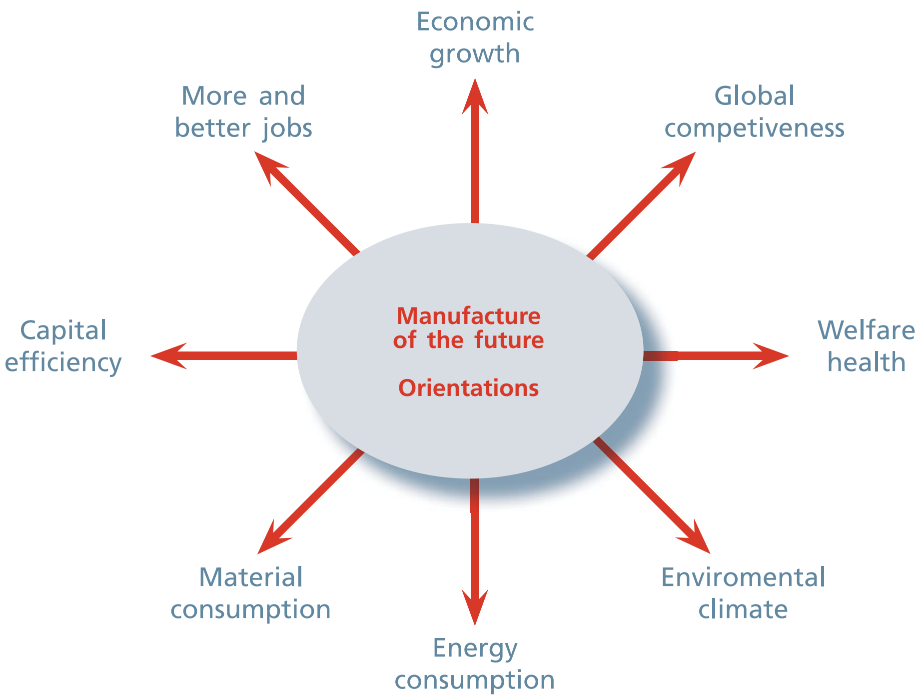
B. Capturing socio-economic value through manufacturing

Many of the recent national analyses of the future of manufacturing focus on the complex challenge of identifying those elements (and associated configurations) of modern manufacturing systems with the potential of capturing significant value for the given country. The contribution of production (and emerging production technologies) to tackling a range of social “grand challenges” has been specifically emphasized. Notably, there is growing emphasis in many countries on identifying aspects of manufacturing that are sources of jobs. Many studies also discuss the importance of manufacturing for specific issues including: trade balance, improved productivity, sustainability and the development of production-related services.

[7] Gary Pisano and Wily Shih (Pisano & Shih, 2009) coined the term “industrial commons” by analogy with common pastures in medieval villages where residents grazed their livestock together. The “industrial commons”provide 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.

Exercises sponsored by the European Commission have emphasized the need for high adding-value in manufacturing for welfare and the economic base of living. A "European Policy for Adding Value" calls for economic growth, competition and high employment.

Figure XI. Orientation towards manufacturing of the future: conflict in strategic objectives



Source: Jovane et al., 2009.

In Germany, the National Academy of Science & Engineering convened leading experts to address challenges to the future of German manufacturing competitiveness (German Academy of Sciences, 2011), in particular, exploring ways to capture added value and employment in a high-wage economy. In Japan, the focus has been on the implications of demographic change, reflected in 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

In Latin America, the report InnovaLatino, (2011) while not explicitly focusing on manufacturing industries, contends that innovation is important not only in economic terms, and highlights employment, wage inequality and firm survival as important aspects related to innovation. The box below presents the report's recommendations to increase innovative activities in Latin America, emphasizing their importance for employment generation.

Box 2. The innovation policy agenda for Latin America

1. Innovation in Latin America starts with people—researchers, entrepreneurs, managers, employees, suppliers and customers of firms. Empowering people to innovate calls for more and better education for all. As countries pursue that educational goal, they will equip their economies to become better able to absorb, adopt, adapt and generate new ideas and technologies.

2. A second group of actors in an innovation system are firms. Businesses are the place where knowledge and ideas are translated into new products, services and business models. Innovation policy should recognize the diversity of firms in terms of size and sectoral specificities, and foster actions and instruments suited to the characteristics of the economy. In particular, targeted support to micro, small and medium-sized enterprises is vital, given their importance for employment generation and due to their vulnerability to failure in their early years.

3. Strengthening institutional and infrastructure capacities for scientific research and developing incentives to support the diffusion and application of scientific outcomes to production development are key elements of success in innovation policies.

4. A tangible and intangible infrastructure for innovation is crucial. It requires investment and the provision of adequate regulatory frameworks. High-speed broadband connections, in particular, offer an important platform for boosting entrepreneurial activity in many countries of the region, but also for the provision of basic public services such as health and education to disadvantaged sectors of the population.

5. As innovation is an inherently risky undertaking which requires long-term financial commitment, public policy must encourage adequate financing to enterprises.

6. Successful innovation policy requires a long-term commitment from legitimate institutions with clear mandates, as well as coordinated action between ministries, agencies and other levels of government, calling for improved means for designing and implementing coherent policies.

7. In addition to coherence among ministries, actors and policy domains, innovation policy implies greater coherence between supply- and demand-side policies. The former typically include funding basic research or increasing levels of schooling; the latter include smart regulations, standards, pricing, consumer education and tax measures.

8. Policy measures to unleash and support entrepreneurial creativity in Latin America cannot ignore policies directed towards the informal sector. Roughly one out of two workers in the region works in the informal sector and in some countries, the majority from middle-class households work in the informal sector. Effective innovation policies cannot overlook this part of the economy.

Source: InnovaLatino, 2011.

C. Potential future opportunities of manufacturing

Many of the recent national analyses on the future of manufacturing highlight industrial activities that are expected to become more prominent in the future as a result of high-level global trends and emerging technological developments. The list of potential future opportunities presented in this chapter is only illustrative and by no means comprehensive; it only captures some of the opportunities identified in the official documents reviewed, complemented with information obtained from relevant industry reports. To reiterate, this report mainly compiles and synthesizes existing work rather than producing new primary data.

Across the documents included in our review, opportunities have been identified where:

- Industry growth is expected to be greater than its observed historical performance. For example, environmental technologies, industries based on emerging life science technologies, electric vehicles and so-called key enabling technologies have been identified as areas of high growth.
- Some countries have a natural competitive advantage vis-à-vis competitors. Particularly in Latin America, the abundance of natural resources, its geographical location and ethnic and biodiversity have been identified as sources of a natural competitive advantage.
- Accumulated industrial capabilities make it conducive to address potential technological gaps in new industrial activities.

C.1. Environmental and energy technology-based industries

Global markets for products and services aimed at minimizing the environmental impact of human activity have grown at a very fast pace and are expected to continue to do so in the coming years (DG Enterprise and Industry, 2010). The "eco-sector" covers areas such as water management, renewable energy recycling, and waste management. Its global market is currently estimated at €1 trillion and is expected to reach €7 trillion worldwide over the next 20 years (Bloomberg, 2011). Annual growth of eco-industries in the European Union has averaged 8 per cent over the last five years (DG Enterprise and Industry, 2010). Faster, better, cheaper and greener low-impact materials are being developed to move towards low resource production, to reduce waste and respond to resource scarcity (Future Manufacturing Council, 2011).

C.2. Wind power industry

The wind power industry has been growing rapidly over the last decade and manufacturing companies are beginning to take advantage of this growth. The annual growth rate of the industry has been increasing since 2001, peaking at 31.7 per cent in 2009. Worldwide wind power capacity was estimated at over 237 GW in 2011 (table 3). The leading countries, China, Germany, India, Spain and the United States represent a total share of 74 per cent of total global wind capacity. The highest growth rate by country in 2010 was registered in Romania, which increased its capacity by 40 (WWEA, 2011).

Table 3. Global installed wind power capacity—regional distribution

Region	2010 (MW)	2011 (MW)
Total Latin America	1 997	2 889
Total Canada and United States	44 306	52 184
Total Europe	86 647	96 606
Total Asia	61 106	82 029
Total Africa and Middle East	1 065	1 093
Total Pacific Region	2 516	2 859
World Total	**197 637**	**237 669**

Source: GWEC (2011).

Latin America lags far behind the rest of the world in the commercial use of wind power, with its contribution estimated at only 1.2 per cent of the global installed wind power capacity in 2011. However, the region has recently made some progress towards capturing the opportunities its enormous wind power potential offers. Even though growth in 2011 (902 MW) was still small when compared with the leading regions, such as Europe and Asia, in absolute terms, there was an increase of over 50 per cent in total installed capacity in 2010 (GWEC, 2011).

C.3. Solar power industry

Solar photovoltaic (PV) is now the third most important renewable energy in terms of globally installed capacity after hydro and wind power (EPIA, 2011). PV companies manufactured a record 24,000 MW equivalent of PV cells worldwide in 2010, more than double their output in 2009. The average annual growth rate of the global photovoltaic industry exceeds 25 per cent (European Commission, 2011). The worldwide hardware market (e.g. solar panels, towers) is expected to grow rapidly, with some analysts estimating growth from US$ 33 billion in 2008 to over US$ 100 billion in 2013 (White House, 2009). According to estimates by the International Energy Agency, PV will provide around 11 per cent of global electricity production and prevent 2.3 gigatonnes (Gt) of CO_2 emissions per year by 2050 (IEA, 2010).

The PV value chain is divided into upstream and downstream activities. The former include the manufacturing of polysilicon, inverters, wafers, cells, photovoltaic cells (c-Si panel cells), mounting and tracking systems and electrical components, while the downstream activities include project development, wholesale distribution, design and engineering, construction and maintenance. The manufacturing of polysilicon and inverters is highly concentrated. According to (EPIA, 2011), about 75 companies are active in polysilicon production worldwide, however, more than 90 per cent of total supply was manufactured by seven major players from Europe, United States and Japan. The same can be said about inverter production; the top-ten companies produced more than 80 per cent of inverters sold on the markets (EPIA, 2011). On the other hand, the market is more segmented among the manufacturers of wafer, cell and thin film modules. Worldwide, more than 200 companies produced wafers and around 1,000 companies produced photovoltaic cells in 2010. About 160 companies were active in the manufacture of thin film modules (EPIA, 2011).

Only four countries have a cumulative installed PV capacity of 1 GW or above: Germany (5.3 GW), Spain (3.4 GW), Japan (2.1 GW) and the United States (1.2 GW). They account for almost 80 per cent of total global capacity (IEA, 2010). Japan became the third largest market in 2009 with 484 MW installed capacity and shows more growth potential due to favourable government support. In the United States, around 475 MW of PV capacity was installed in 2009 alone. The United States appears to be a potential leading market in coming years, with many ground-mounted systems (solar panels held in place by racks or frames that are attached to the ground) commencing production in 2010 (EPIA, 2011).

There is evidence of the high potential of the solar power industry in Latin America. Brazil's northeast region and the Atacama Desert in Chile represent what is called the "sunbelt"—an area with some of the highest levels of solar radiation in the world. Increasing sources of funding by international agencies and private capital markets have been attracted by the region's needs and potential. Some of the leading global solar industry players are already making important investments in the region. Various Chinese companies are providing solar panels for the Latin American market as well as equipment for the manufacturing of such panels. For example, the Chinese company Jinko Solar is becoming an increasingly powerful player in Brazil, Argentina and Chile.

C.4. Life science industries

Biomanufacturing

The global biopharma industry, led by the United States, was worth US$ 800 billion in 2010 and is growing at 16 per cent annually—over twice as fast as the pharmaceutical drug market (Reynolds, 2010). In the industrial biotechnologies sector, the value of biochemicals (other than pharmaceuticals) will increase from 1.8 per cent of all chemical production in 2005 to between 12 per cent and 20 per cent by 2015 (OECD, 2009).

Over the last 30 years, the field of agricultural biotechnology has developed rapidly due to the greater understanding of DNA. Genetic engineering is one of the modern agricultural biotechnology tools that have the ability to manipulate individual genes and to transfer genes between species. In 2011, biotech crops reached 160 million hectares, up 12 million hectares from 2010—an 8 per cent increase (ISAAA, 2012). Developing countries grew close to 50 per cent of global biotech crops in 2011 and for the first time are expected to exceed industrial countries' hectarage in 2012. The five leading developing countries in biotech crops are China and India in Asia, Brazil and Argentina in Latin America, and South Africa in Africa. Collectively, these countries, which are home to around 40 per cent of the global population, grew approximately 71.4 million hectares, 44 per cent of the world's total (ISAAA, 2012).

As countries seek to reduce CO_2 emissions from the transportation sector and address their dependence on petroleum-based fuels, biofuels are gaining increasing attention. Many countries have established ambitious production targets as a first step towards the development of renewable sources for transportation fuels. Driven by policy mandates and renewable energy goals around the world, global ethanol and biodiesel productions are projected to continue their rapid growth: they are expected to reach, respectively, some 155 bnl[8] by 2020 (up from 92 bnl in 2008), and 42 bnl by 2020 (up from 18 bnl in 2008). Brazil, India and China are projected to account for 85 per cent of ethanol production in the developing world by 2020 (OECD & FAO, 2011). According to some estimates, converting biomass into fuels, energy and chemicals has the potential to generate over US$ 230 billion to the global economy by 2020.

Box 3 presents an overview of the biotechnology activities in Brazil, including a description of a number of government initiatives that have been put into place to support them.

Box 3. Biotechnology in Brazil

Brazil is a country with a wide range of biotechnology opportunities, especially in agriculture, health and the environmental industries.

The geographic distribution of biotech companies reveals a concentration in the Southeast (São Paulo, Minas Gerais, Rio de Janeiro), with companies operating mainly in human health (39.7 per cent), reagents and animal health (27.4 per cent), bioenergy and environment (14.8 per cent) and agriculture (9.7 per cent). The vast majority (85 per cent) are micro and small enterprises with up to 50 employees, and 58 per cent have annual revenues of no more than US$ 1.5 million (BRBIOTEC, 2011a). Overall, this sector remains very young, with more than 60 per cent of the enterprises founded in or after the year 2000 (BRBIOTEC, 2011a).

The number of biotech companies in the country has increased steadily since the 1990s, reaching a peak in 2008. In the agri-biotech industry, Brazil is the second largest grower of biotech crops in the world, after the United States, producing 15 per cent of the global hectarage in 2011 (ISAAA1, 2012). In the bioenergy sector, it is estimated that Brazil was the second largest producer of ethanol in 2008, with a 28 per cent share of global production, and it was among the world's largest producer of biodiesel, just after the United States and Argentina (OECD & FAO, 2011).

There is a visible increase in the number of Masters and PhD graduates (55 per cent and 50 per cent, respectively) over the last decade, around 35 per cent of which were from such areas as biology, health and agricultural studies (BRBIOTEC, 2011b). The majority of biotech firms in the country (70 per cent) are working in collaboration with universities and research centres in product and process development projects.

[8] Billion litres.

Box 3. Biotechnology in Brazil *(continued)*

In the health biotech industry, Brazil, along with India and the Russian Federation, is one of the leading locations for outsourcing of clinical trials. Brazil has benefited from its infrastructure, short approval times and improved regulatory and compliance system in terms of attracting such activities. Moreover, Brazil has a large, diverse, multiethnic population, and is affected by some of the illnesses typical in developing countries, allowing biopharmaceutical companies to study a wide range of diseases.

The substantial role state-owned biopharmas in Brazil have had in the past has diminished, leaving space for the development of the private sector. However, the public sector still controls the development and production of vaccines and basic medicines considered essential for public health, covering 95 per cent of the national human vaccine market. Fiocruz and the Butantan Institute are pioneering vaccines for tropical infectious diseases that have been ignored by the international health community due to their relatively small capital returns of investment (Ministry of Health of Brazil, 2010).

Because the average risk, cost and time of drug development for biopharmaceuticals is high, small Brazilian companies have recurred to reverse engineering of international pharmaceuticals to manufacture and market new medicines and vaccines for the Brazilian market. This has provided a substantial learning effect and facilitated the adoption of new technology and the transition into more sophisticated areas. For example, this strategy was adopted by FK Biotech, which has developed capacities to move from manufacturing of monoclonal antibodies to the more advanced area of cancer vaccines development.

Over the past decade, Brazil has established government initiatives to support the development of biotech enterprises. President Lula signed a decree in 2007 outlining a development policy for the biotechnology industry in the country, The National Policy for Biotechnology. The plan calls for investments of US$ 5.8 billion over the next decade, with the aim of doubling the number of start-ups and creating 20 PhD programmes over a five-year period (Avila, Cuhna, & Yeganiantz, 2010). Moreover, the government has adopted the Brazilian Innovation Law, considered the first innovation law in Latin America. It allows public funds to be spent on industrial projects and grants foreign firms access to the Brazilian market for an initial period of five years in exchange for technological transfer for local manufacture.

The Agency for Studies and Projects (FINEP), whose main goal is to secure a range of facilities for start-ups with "high value added potential", is the primary source of grants for most companies in the biotech private sector in their initial phases. More than half of the companies have benefited from resources from FINEP and nearly half of the companies have received funding from another federal or state institution (BRBIOTEC, 2011a). Furthermore, with the support of IMF, FINEP launched a new programme called INOVAR, aimed at addressing funding gaps and challenges faced by technology-based small and medium-sized companies. The programme consisted of two phases (2001-2006 and 2007-2012) and has been recognized as a model for stimulating a venture capital and private equity funding system.

Medical devices

The global medical devices industry is highly competitive and highly innovative, with estimated worldwide sales of more than US$ 300 billion in 2011. According to some estimates, the global medical device market is expected to approach US$ 350 billion by 2016—an annual average growth of 5 per cent from 2011 (Episcom Healthcare Intelligence, 2012).

The medical devices industry is divided into different segments including cardiology, oncology, neuro, orthopaedic, aesthetic devices and health-care IT. The expansion of the medical industry is driven by three factors:

- The ageing of the population: over 20 per cent of the world's population will be aged 60 or above by 2050
- The emergence of a wealthier middle class in developing countries, especially India and China
- Projected overall higher living standards.

Companies can take advantage of novel biomaterials, high throughput biochemical processes and genomic technologies for smarter design of medical drugs and other chemicals with applications in agriculture and industry (Future Manufacturing Council, 2011). Biomaterials, which cover products as diverse as hip implants, cell therapy technologies and innovative drug delivery systems, had a global market of US$ 25.6 billion in 2008. This is expected to reach US$ 65 billion by 2015, with a compound annual growth rate of 15 per cent from 2010 to 2015 (MarketsandMarkets, 2011). Orthopaedics and cardio-vascular are the dominant areas and currently comprise 75 per cent of all revenues (Future Manufacturing Council, 2011). In addition, advances in fields such as epidemiology, computation, imaging, sensing and pharmacology will lead to cost-effective and efficient health management, high value in diagnostics, data and service delivery (Government Office for Science, 2010).

C.5. Electric vehicles

By 2050, the global fleet of light duty vehicles is expected to triple and its CO_2 emissions are expected to double. Therefore, addressing fuel efficiency in road transport is becoming increasingly important in international environmental, energy and climate change agendas (UNEP, 2009). Traditional automobile production is undergoing a profound transition as new developments take place in battery technologies and design is geared towards cleaner vehicles, improved efficiency and reduced emissions.

Many automakers have already introduced hybrid electric vehicles (HEVs) into the market. These vehicles are powered through a combination of traditional internal combustion and electric engines. However, the global production of hybrid cars is still very small compared to the number of traditional cars. In 2007, a total of 541,000 hybrids were produced, accounting for around

0.80 per cent of global light vehicle assembly. This represents a major increase from the 0.25 per cent (150,000 vehicles) hybrid share in 2004 (UNEP, 2009). Of the 2007 global hybrid production, 52 per cent (280,000 vehicles) were Toyota Prius models, 181,200 of which were sold in the United States (EDTA, 2008). The production of hybrid vehicles is expected to increase to 1.7 million by 2014 (PwC, 2007).

However, HEVs are only considered the first step towards a fully electric vehicle (EV). A small but visible group of United States start-ups, such as Tesla Motors, Fisker Automotive, Coda Automotives and Phoenix Motorcars, is beginning to produce fully electric cars. While the EV market is likely to develop slowly in the next five to seven years, production projections are as high as 100,000 vehicles per year by 2015 (White House, 2009).

Brazil currently manufactures a limited number of electric vehicles. The Brazilian subsidiary of Fiat currently produces fully electrical vehicles, the FIAT Palio Weekend model. These are the first all-electric cars produced in Latin America. However, due to its estimated selling price starting from US$ 36,000, this car is only expected to be attractive to a relatively small customer base.

Batteries for electric vehicles

An all-electric vehicle derives all its power from its rechargeable battery as it does not carry an internal combustion engine, fuel cell or fuel tank. Lithium-ion batteries are rapidly becoming the industry standard for the next generation of electric vehicles. Over the next decade, the demand for lithium is expected to grow exponentially, benefiting the mining industry in Chile, Argentina and Bolivia. In 2011, Chile and Argentina were the largest suppliers of lithium globally; together, they were responsible for approximately 46 per cent of the world's total lithium production (United States Geological Survey, 2012).

While South America's position is dominant in the production of lithium, it is even more so in terms of its reserves. According to some estimates, Chile, Argentina and Bolivia together account for more than 57 per cent of the world's lithium reserves. Some countries have already identified the opportunity to capitalize on this advantage by moving up the value chain—from the production of lithium carbonate and chloride to the production of lithium batteries.

C.6. Key enabling technologies

The so-called key enabling technologies (KETs) have attracted considerable attention in terms of both their projected growth as independent industries as well as their potential to increase productivity and value added in existing ones. Within the industrial biotechnologies sector, the value of biochemicals (other than pharmaceuticals) is expected to increase from 1.8 per cent of all chemical production in 2005 to between 12 per cent and 20 per cent by 2015 (OECD, 2009). Similarly, the conversion of biomass into fuels, energy and chemicals has the potential to generate over US$ 230 billion by 2020 (WeF, 2010). Products underpinned by nanotechnology are projected to grow from a volume of US$ 254 billion in 2009 to US$ 2.5 trillion by 2015 (European Commission, 2011).

Furthermore, KETs-based industries accounted for several million jobs in the EU alone in the past decade. According to European Commission estimates, the micro-nanoelectronics industry (materials, equipments and semiconductors) directly employ around 200,000 people and indirectly create around 1 million jobs (European Commission, 2011). It is estimated that by 2015, there will be 400,000 nanotechnology-related jobs in the EU linked to existing industries (e.g. process and manufacturing, automotive, ICT, medical) in which the EU already has a leading position. In addition, it is estimated that by 2015, approximately 2 million nanotechnology-related workers will be needed worldwide (European Commission, 2011). In addition, approximately 5,000 photonics companies in the EU, mostly SMEs, directly employ 300,000 people, and more than 2 million employees in the European manufacturing sector depend directly on photonics products (European Commission, 2011).

Table 4. Estimated global market potential of key enabling technologies

KETs	*Current market size (~2006/2008) USD billion*	*Expected market size (~2012/ 2015) USD billion*	*Expected compound annual growth rate*
Nanotechnology	12	27	16%
Micro and nanoelectronics	250	300	13%
Industrial biotechnology	90	125	6%
Photonics	230	480	8%
Advanced materials	100	150	8%
Advanced Manufacturing Systems	150	200	6%
Total	**832**	**1 282**	**5%**

Source: European Commission, 2011.

KETs have the potential to generate new markets and strengthen existing ones by increasing productivity and efficiency levels through knowledge spillovers and innovation (European Commission, 2011). They furthermore have the potential to enable the next generation of more complex, higher value added products. For example, the development of electric cars may depend on the integration of a number of KETs: advanced materials for batteries, microelectronic components for power electronics, photonics for low consumption lighting and industrial biotechnologies for low friction tyres (European Commission, 2011).

D. Conclusions

The previous section identifies potential future opportunities in a range of industries from environmental and energy technology-based industries to life science industries. Though the list of industries presented here is by no means exhaustive, it does provide a glimpse of the future direction global manufacturing might take. Manufacturing has undergone a profound transformation over the last decades in terms of structure, technology, sectoral interlinkages and boundaries, and is increasingly being understood as a system with complex interdependencies across a range of sectors that contribute a number of components, production systems and subsystems, materials and producer services. Hence, without a conceptual framework that can account for the different components that make up the manufacturing system as a whole, it will not be possible to fully understand how economies might enhance manufacturing competitiveness, address technological gaps and devise strategies and policies to capture value from modern value chains.

Such a conceptual framework, in turn, must be built on the "megatrends" and drivers that affect global industrial systems. Hence, they are determined by globalization, environmental, economic and social sustainability, the ageing of society and increasing urbanization. Globalization has fostered the development of global value chains and has thus facilitated the rapid integration of emerging countries into the global economy. This has implications on how firms operate and the strategies they adopt to remain competitive as manufacturing activities are becoming increasingly fragmented and trade in intermediate inputs is growing. Sustainable manufacturing extends to the entire system of integrated components, energy and transportation required to assemble the final product and deliver it to customers. Consequently, the environmental, economic and social dimensions of sustainability also shape conceptual frameworks elaborated to increase manufacturing competitiveness. Calls are mounting to reduce the environmental impact from production systems to "near zero", which requires drastic changes in product design, production systems and the overall production process to reduce the energy intensity of manufacturing activities and the amount of pollutants such they create. Changes in one dimension will affect the other two dimensions; the well-being of people cannot be sustained without a healthy environment and a dynamic economy.

There is increasing pressure to attain economic growth while at the same time reducing the consumption of scarce resources and minimizing waste. Manufacturing systems will therefore require new materials, methods, processes and technologies to address future environmental challenges and ensure that both the economic and ecological dimensions of sustainability are achieved. Hence, firms will need to engage in the production of goods and services that have the least possible negative impact on the environment and must seek new ways to minimize resource and energy consumption such as reducing their total carbon footprint, using environmentally friendly materials, ensuring their products can be recycled, etc. These environmental requirements will require radical changes in product design, production systems and the production process and are best achieved through the development and use of new technologies to improve productivity, increase the efficiency of manufacturing processes and ensure that products remain affordable by lowering production costs.

Social sustainability can only be realized if manufacturing is competitive and able to generate the necessary income to pay knowledge workers and to invest in (environmentally-) and worker friendly factories. Social investments will be crucial to effectively deal with the demographic challenges the future will bring, such as the ageing of the population, which will require increased spending on welfare and health systems. The resulting decrease of the labour supply and the widening skill gap due to the loss of tacit knowledge of older employees will affect the way firms hire, train and retrain and compensate their future workforce. "Human-centred manufacturing" emphasizes people's unique role as innovators and decision-makers in firms, and production systems can either be based on the "user focus", which prioritizes how technology can support human work, or the "human-centred focus", which concentrates on how humans interact with technology and places human skills, creativity and knowledge at the centre of technological systems. Manufacturing firms will need to be demographically balanced, i.e. adequate measures need to be taken to ensure that the knowledge of older employees is captured, transferred and reused.

These future challenges will require industries to enhance and develop new qualities and features to remain competitive. Globalized value chains and changing consumer habits as general prosperity and income increases in emerging countries will require more flexible production systems that can minimize the effects of disruptions in the value chain and adapt production quantities according to demand fluctuations. As disposable income in developing economies rises, demand for individualized products and services increases, which represents a major opportunity for manufacturers of higher value-added goods. With continuous changes in product volumes and mix, manufacturing firms will need to respond to a much wider range of product specifications within short periods of time at affordable prices. To deal with these challenges, firms will need to implement technological solutions that can ensure the flexibility and continuous adaptation of production systems. Advanced manufacturing techniques such as additive manufacturing and laser processing can help create complex, custom products and replacement parts that are needed quickly in low volumes.

The competitiveness of future manufacturing firms will be increasingly linked to their ability to rapidly transfer developments in S&T into their processes and products. Hence, firms that adopt an open innovation model, namely a process designed to accelerate innovation by allowing them to share and integrate resources with partner organizations and internal business units, will benefit from shorter times to market, the acquisition of new technologies and ideas, access to additional expertise and access to new markets. In other words, the likelihood of success of innovative products is based on cooperation along the supply chain networks in which participants are able to match their technological knowledge with complementary expertise from other areas. This report has found that a number of technology areas, including nanotechnology, biotechnology, photonics and advanced materials, are expected to play an increasingly prominent role in enabling the production-related solutions and concepts identified. They represent future areas of high growth for manufacturing, but firms will only be able to compete in these areas and remain competitive if they can build and upgrade their production-related capabilities and address technological gaps, though the requirements will vary from firm to firm depending on a number of factors such as the given industry's own internal dynamics and the firm's position in the value chain. However, even though the requirements for firms to remain competitive in the future may vary, they will need to take account of the increasing fragmentation of manufacturing activities, the growing mix of product requirements and the accelerated rate of technological innovation and develop ever more complex manufacturing designs, products, processes and operations to remain in the game.

References

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

Avila, A., Cuhna, E., & Yeganiantz. (2010). *Biotechnologies in Brazil*.

BCG. (2010). *Winning in Emerging Market Cities: A Guide to the World's Largest Growth Opportunity*. Boston, USA: Boston Consulting Group.

Bloomberg. (2011). *Global Renewable Energy Market Outlook*. Bloomberg New Energy Finance.

BRBIOTEC. (2011a). *Innovation is in our DNA: Brazil's Biotech Initiatives*.

BRBIOTEC. (2011b). *Brazil Biotech Map 2011*. Brazil Biotech. Retrieved from http://www.clustercollaboration.eu/documents/270120/0/Brazil_Biotec_Map_2011.pdf

CME. (2005). *The Future of Manufacturing in Canada: Perspectives and Recommendations on Workforce Capabilities*. 20/ 20 Building our Vision for the Future. Canadian Manufacturers and Exporters.

Dediu, H. (2012). When Will Smartphones Reach Saturation in the US? Retrieved from http://www.asymco.com/2012/04/11/when-will-smartphones-reach-saturation-in-the-us/

DG Enterprise and Industry. (2010). EU Manufacturing Industry: What are the Challenges and Opportunities for the Coming Years? Presented at the 2nd High Level Conference on Industrial Competitiveness, Brussels, Belgium: European Commission.

Dreher, C. (2007). *Manufacturing Visions Policy Summary and Recommendations*. Karlsruhe: Fraunhofer Institute Systems and Innovation Research.

EDTA. (2008). *Hybrid Vehicle Sales Information: Figures 2008*. Electric Drive Transport Association.

EFFRA. (2011). *Roadmap: Factories of the Future Beyond 2013*. European Factories of the Future Research Association.

ElMaraghy, H. (2005). Flexible and Reconfigurable Manufacturing Systems: Paradigms of Manufacturing, A Panel Discussion. Presented at the 3rd Conference on Reconfigurable Manufacturing, University Ann Arbor, Michigan.

ElMaraghy, H. (2006). *Flexible and Reconfigurable Manufacturing Systems Paradigms*. Springer Science+Business Media, LLC.

EPIA. (2011). *Solar Generation 6: Solar Photovoltaic Electricity Empowering the World*. European Photovoltaic Industry Association.

Episcom Healthcare Intelligence. (2012). *The Outlook for Medical Devices in Latin America to 2016*.

European Commission. (na.). Mandate to the European Standard Bodies for a Guidance Document in the Field of Safety and Usability of Products by People with Special Needs (e.g. elderly and disabled).

European Commission. (2009). *Monitoring Industrial Research: The 2009 EU Industrial R&D Investment Scoreboard*. Seville, Spain: European Commission, Joint Research Centre Directorate General Research.

European Commission. (2011). *Key Enabling Technologies.Final Report by the High-Level Group on Key Enabling Technologies*. European Commission.

Fraunhofer IPA. (2007). *Manufuture Workprogramme "New Production". European Commission Project Leading European RTD Sustained High Value Innovative Production for Manufuture*. Fraunhofer Institute for Manufacturing Engineering and Automation.

Future Manufacturing Council. (2011). *Trends in Manufacturing to 2020: A Foresighting Discussion paper*. Canberra, Australia: Future Manufacturing: Department of Innovation, Industry, Science and Research.

German Academy of Sciences. (2011). *Wertschöpfung und Beschäftigung in Deutschland [Value Added and Employment in Germany]* (Report of the Acatech Workshop).

Geyer, A., Scapolo, F., Boden, M., Döry, T., & Ducatel, K. (2003). *The Future of Manufacturing in Europe 2015-2020: The Challenge for Sustainability*. European Commission, Insitute for Perspective Technological Studies.

Gibson, I., Rosen, D., & Stucker, B. (2010). *Additive Manufacturing Technologies*. Springer Science+Business Media, LLC.

Goldman Sachs Investment Research. (2011). *Equity Research: The Best Fortnight Thoughts*. The Goldman Sachs Group, Inc.

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

GWEC. (2011). *Global Wind Report: Annual Market Update 2011*. Brussels, Belgium: Global Wind Energy Council.

High Level Group on Key Enabling Technologies. (2010). *Report by the Working Team on Advanced Manufacturing Systems* (Report for the European Commission).

High Level Group on Key Enabling Technologies. (2011). *Final Report of the High-Level Group on Key Enabling Technologies* (Report for the European Commission).

IDA. (2012). Emerging Global Trends in Advanced Manufacturing. Institute for Defense Analyses Paper P-4603 for the Office of the Director of National Intelligence.

IEA. (2010). *Technology Roadmap: Solar Photovoltaic Energy*. International Energy Agency.

IfM. (2009). Creating an Environment for Open Innovation. Institute for Manufacturing, Cambridge University. Retrieved from http://www.ifm.eng.cam.ac.uk/working/briefings/v1n4_ifm_briefing.pdf

InnovaLatino. (2011). *Fostering Innovation in Latin America*. Madrid, Spain: OECD; INSEAD; Fundacion Telefonica.

ISAAA. (2012). Biotech Facts & Trends 2012. *International Service for the Acquisition of Agri-Biotech Applications*. Company Website. Retrieved from http://www.isaaa.org/

ITIF. (2011). *Case For A National Manufacturing Strategy. The Information Technology and Innovation Foundation*. Washington D.C.: The Information Technology & Innovation Foundation.

Jovane, F., Westkämper, E., & Williams, D. (2009). *The ManuFuture Road: Towards Competitive and Sustainable High-Value-Adding Manufacturing*. Springer Verlag.

Lettl, C. (na). *User-Centred Innovation: How Innovation Moves Out of Manufacturers' Labs*. University of Aaarhus, Denmark.

Lilien, G., Morrison, P., Searls, K., Sonnack, M., & von Hippel, E. (2002). Assessment of the Lead User Idea-Generation Process for New Product Development. *Management Science*, *48*(8), 1042–1059.

Malhotra, V., Raj, T., & Arora, A. (2009). Reconfigurable Manufacturing System: An Overview. *International Journal of Machine Intelligence*, *1*(2), 38–46.

ManuFuture. (2006). *Strategic Research Agenda—Assuring the future of manufacturing in Europe: Report of the High Level Group*. Retrieved from http://www.manufuture.org/

ManVis. (2006). Report 6 – Policy Summary and Recommendations. Manufacturing Visions. Retrieved from http://foresight.jrc.ec.europa.eu/documents/PolicyPaper_final.pdf

MarketsandMarkets. (2011). *Global Biomaterials Market (2010-2015)*. Retrieved from http://www.marketsandmarkets.com/Market-Reports/biomaterials-393.html

MATES. (2012). Multi Agency Tissue Engineering Science. Company Website. Retrieved from http://www.tissuegrowth.com/?gclid=CPK80OCChbECFQpd3wodHCRPBA

Maula, M., Keil, T., & Salmenkaita, J. (2005). Open Innovation in Systemic Innovation Contexts.

McKinsey. (2009). Building a Flexible Supply Chain for Uncertain Times. *McKinsey Quarterly*.

Ministry of Health of Brazil. (2010). *Role of Partnerships in Developing Innovative Vaccines: Brazil*. Presented at the SAGE Meeting. Retrieved from http://www.who.int/immunization/sage/nov2010_fostering_partenrships_guimaraes.pdf

Miroudot, S., Lanz, R., & Ragoussis, A. (2009). *Trade in Intermediate Goods and Services*. OECD Trade Policy Working Papers.

Mueller, J., & Stewart, G. (2011). Balancing the Risks, Benefits and Costs of Homeland Security. *Home Security Affairs Journal*, *7*(Article 16).

Munich Re, & Thailand Insurance Commission. (2011). *Natural Catastrophes 2011: Analyses, Assessments, Positions*. Munich Re.

Nanto, D., Cooper, W., & Donnelly, J. (2011). Japan's 2011 Earthquake and Tsunami Economic Effects and Implications for the United States. Retrieved July 6, 2012, from http://www.fas.org/sgp/crs/row/R41702.pdf

O'Sullivan, E. (2011). *A Review of International Approaches to Manufacturing Research* (Institute for Manufacturing Report for the UK Engineering and Physical Sciences Research Council). Cambridge, UK: Institute for Manufacturing, University of Cambridge.

O'Sullivan, Eoin, & Mitchell, N. (2012). *International Approaches to Understanding the Future of Manufacturing* (A Report to the Government Office of Science). Cambridge, UK: University of Cambridge.

OECD. (2007). *Globalisation and Regional economies: Can OECD Regions Compete in Global Industries?* Paris: Organisation for Economic Co-operation and Development.

OECD. (2009). *The Bioeconomy to 2030: Designing a Policy Agenda (Main Findings and Policy Conclusions)*. OECD International Futures Project. Paris, France: Organisation for Economic Co-operation and Development.

OECD. (2010). *The Emerging Middle Class in Developing Countries*. Paris: Organisation for Economic Co-operation and Development.

OECD. (2011). *OECD Due Diligence Guidances for Responsible Supply Chains of Minerals from Conflicted-Affected and High-Risk Areas*. Organisation for Economic Co-operation and Development.

OECD. (2012). OECD Work on Patent Statistics. Organisation for Economic Co-operation and Development. Retrieved from http://www.oecd.org/document/10/0,3746,en_2649_33703_1901066_1_1_1_1,00.html

OECD & FAO. (2011). *Agricultural Outlook 2011-2020: Chapter 3 Biofuels*. OECD/FAO.

PwC. (2007). *An Overview of Industry Data, Trends and Financial Reporting Practices: Global Automotive Financial Review*. PricewaterhouseCoopers International Limited.

PwC. (2011). *The World in 2050 - The Accelerating Shift of Global Economic Power: Challenges and Opportunities*. PricewaterhouseCoopers International Limited.

Reynolds, E. (2010). *Institutions, Public Policy and the Product Life Cycle: The Globalization of Biomanufacturing and Implications for Massachusetts*. MIT.

Rolls Royce. (2012). Composites. *Company Website*. Retrieved from http://www.rolls-royce.com/technology_innovation/material_tech/composites.jsp

Royal Academy of Engineering. (2009). *Synthetic Biology: Scope, Applications and Implications*. London: Carlton House.

Singer, E. (2011). *Why Is Biomanufacturing So Hard?*

STPI. (2010). White Paper on Advanced Manufacturing Questions. Presented at the The Advanced Manufacturing Workshop of the President's Council of Advisors on Science and Technology's Study on Creating New Industries through Science, Technology and Innovation, Science and Technology Policy Institute.

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

Sturgeon, T., & Kawakami, M. (2010). *Global Value Chains in the Electronics Industry. Global Value Chains in a Post Crisis World : A Development Perspective*. Washington D.C.: World Bank Group.

Sugar, W., & Boling, E. (1995). User-Centred Innovation: A Model for Early Usability Testing. Presented at the Annual National Convention for Educational Communications and Technology (AECT), Anaheim, California.

Tassey, G. (2010). Rationales and mechanisms for revitalizing US manufacturing R&D strategies. *The Journal of Technology Transfer*, *35*(3), 283–333.

Teknikföretagen Production Research. (2008). *Swedish Production Research 2020: Strategic Research Agenda*.

U.S. Dept of Commerce. (2005). *Top US Export Prospects: Brazil (Medical Equipment)*.

U.S. Geological Survey. (2012). *Statistics and Information on the Worldwide Supply, Demand and Flow of Lithium*. U.S. Geological Survey.

UN. (2011). *World Populations Prospects: The 2008 Revision Population Database*. New York and Geneva: United Nations Department of Economic and Social Affairs.

UNEP. (2009). *Hybrid Electric Vehicles: An Overview of Current Technology and its Application in Developing and Transition Countries*. Nairobi, Kenya: United Nations Environment Programme.

US Intelligence National Council. (2008). *Global Trends 2025: A Transformed World*. Washington, D.C.

USTPO. (2011). *Patents by Country and Year - All Patent Types (December 2011)*. Alexandria, VA: U.S. Patent and Trademark Office (Patent Technology Monitoring Team).

van der Zee, F., & Brandes, F. (2007). *Manufacturing Futures for Europe—A Survey of the Literature* (TNO Background Report).

Wang, Z. (2004). *What is Nanotechnology? And How Will This Small Wonder Make a Big Change in Manufacturing?* in Shapira, P.; Youtie, J.; and Urmanbetova, A., Advanced Technology and the Future of US Manufacturing. Prepared for: Futures Group Manufacturing Extension Partnership of the National Institute of Standards and Technology (NIST).

WeF. (2010). *The Future of Industrial Biorefineries*. Geneva, Switzerland: World Economic Forum.

WeF. (2012). *New Models for Addressing Supply Chain and Tranport Risk*. Geneva, Switzerland: World Economic Forum.

White House. (2009). *A Framework for Revitalizing American Manufacturing*. Washington, D.C.: White House, Executive Office of the President. Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/20091216-manufacturing-framework.pdf

WWEA. (2011). *World Wind Energy Report 2010*. Bonn, Germany: World Wind Energy Association.

Yakimov, G., & Woosley, L. (2010). *Innovation and Product Development in the 21st Century*. MEP (Manufacturing Extension Partnership).

Annex. List of international manufacturing policy exercises addressing future manufacturing trends

This study has been informed, primarily, by international exercises addressing challenges and opportunities in future manufacturing systems identified in a range of nations. As mentioned earlier, large variation exists between these exercises in terms of methodology, national context and stakeholder perspective.

The various types of exercises identified include:

- Lobbying/positioning documents
- Agency white papers
- National S&T Plans
- National academy studies
- Research agency division strategies
- National symposia presentations & reports
- Workshop/symposia proceedings
- Consultancy reports
- Academic papers

The various types of methodologies used in these exercise include:

- Panels/workshops/consultations
- Technology foresights
- Surveys/Delphi studies
- Expert groups
- Scenarios
- Roadmaps

Stakeholders whose perspectives are reflected in the studies include:

- Manufacturing firms
- Government agencies
- Academia
- Learned societies
- Industry organisations
- Think tanks

The following table presents a summary of the studies that have been identified and analysed for the purposes of this report.

Country	*Year*	*Exercise type*	*Lead author type*	*Title*
Australia	2011	Discussion paper	Government agency	Trends in Manufacturing to 2020 (Future Manufacturing Council, Department of Innovation, Industry, Science and Research, 2011)
Australia	2006	Positioning/ lobbying document	Industry association	Manufacturing Futures: Achieving Global Fitness (The Australian Industry Group, 2006)
Canada	2005	Positioning/ lobbying document	Industry association	The future of manufacturing in Canada—Perspectives and Recommendations on International Business Development (Canadian Manufacturers and Exporters, 2005)
China	2011	Technology roadmap	Learned society	China: Advanced Manufacturing Technology in China: A Roadmap to 2050 (Chinese Academy of Sciences, 2011)
China	2009	Foresight study	Learned society	Technological Revolution and China's Future-Innovation 2050 (Chinese Academy of Sciences, 2009)
Denmark	2008	Research strategy (consultation)	Government agency	Research 2015: A Basis for Prioritisation of Strategic Research (Danish Agency for Science, Technology and Innovation, 2008)
European Union	2010	White paper	EC (DG Enterprise and Industry)	EU Manufacturing Industry: What are the Challenges and Opportunities for the Coming Years? (DG Enterprise and Industry, 2010)
European Union	2009	Expert report	Academia	The ManuFuture Road (Jovane et al., 2009)
European Union	2007	Roadmapping	Public research centre	ManufutureWorkprogramme "New Production" (Manufuture, 2007)
European Union	2007	Scenarios study	Consultancy	The Future of Manufacturing in Europe (Brandes et al, 2007)
European Union	2007	Literature review	Consultancy	Manufacturing Futures for Europe—A Survey of the Literature (Van der Zee and Brandes, 2007)
European Union	2007	Research strategy	Public research centre (Fraunhofer)	Manufacturing Visions: A Holistic View of the Trends for European Manufacturing (Dreher, 2007)
European Union	2007	Literature review	Academia	The Future of Manufacturing: Survey of International Technology Foresight Initiatives (Montorio and Taisch, 2007)
European Union	2007	Academic article	Academia	Managing knowledge in manufacturing: results of a Delphi study in European manufacturing industry

Country	Year	Exercise type	Lead author type	Title
European Union	2007	Academic article	Academia	Feeling for the future: strategic responses to industrial, economic and technological change in the European instruments and sensors sector
European Union	2005	Delphi survey	Public research centre (Fraunhofer ISI)	Manufacturing Visions (ManVis, 2005)
Germany	2010	Research Strategy (Expert consultation)	Research ministry (Federal Ministry of Education and Research)	Produktionsforschung 2020 [Production Research 2020] (BMBF, 2010)
Ireland	2012	Research strategy	Government think tank	Report of the Research Prioritisation Steering Group
Sweden	2008	Positioning/ lobbying document (on research strategy)	Industry association	Production Research 2020: Strategic Research Agenda (Teknikföretagen, 2008)
Sweden	2000	Technology foresight (“Panel approach”)	Learned society and industry association	Swedish Technology Foresight “The Foresighted Society”: Production System (IVA et al., 2000)
United Kingdom	2010	Technology foresight	Government agency	Technology and Innovation Futures: UK Growth Opportunities for the 2020s (Foresight Horizon Scanning Centre, Government Office for Science, 2010)
United Kingdom	2012	Consultation report	Government agency/academia	A landscape for the future of high value manufacturing in the UK
United States	2012	Literature review and expert consultation	Think tank	Emerging Global Trends in Advanced Manufacturing (IDA for the Office of the Director of National Intelligence, ODNI) [Shipp et al., 2012]
United States	2012	Workshop report	Learned society	Making Things—21st Century Manufacturing and Design: Report of a Symposium (NAE, 2012)
United States	2011	Workshop report	Government agency	Extreme Manufacturing Workshop: Technology Needs for Long-Term US Manufacturing Competitiveness (NIST, 2011)
United States	2011	Expert report	Government agency	Report to the President on Ensuring American Leadership in Advanced Manufacturing (PCAST, 2011)
United States	2011	White paper	Think tank	The Case for a National Manufacturing Strategy (ITIF, 2011)
United States	2011	Expert report	Government agency	Make: An American Manufacturing Movement (US Council on Competitiveness, 2011)
United States	2010	White Papers	Government think tank	White Papers on Advanced Manufacturing Questions for PCAST (STPI, 2010)

Country	*Year*	*Exercise type*	*Lead author type*	*Title*
United States	2009	Workshop report	Government agency	Challenges to Innovation in Advanced Manufacturing: Report of a National Workshop (NIST, 2009)
United States	2009	White paper	Government	A Framework for Revitalizing American Manufacturing (White House, 2009)
United States	2009	Expert interview report	Government	Japan's Manufacturing Competitveness Strategy: Challenges for Japan, Opportunities for the United States (US Dept. of Trade, 2009)
United States	2009	White paper	Thinktank	The Facts about Modern Manufacturing
United States	2008	Scenarios/ Expert consultation	Government think tank	Global Trends 2025: A Transformed World (US National Inteligence Council, 2008)
United States	2008	Research strategy	Government	Manufacturing the Future (NSTC, 2008)
United States	2007	Expert report	Government agency	Future of Manufacturing in the US (Lehtihet et al., for NIST, 2005)
United States	2007	Academic article	Academia	A Brief History of the Future of Manufacturing: US manufacturing technology forecasts in retrospective, 1950-present (Youtie, 2007)
Republic of Korea	2004	Expert panel, Delphi, scenario panel	S&T policy agency	Korea 2030—The Third Korean National Foresight Exercise (Korean Institute for S&T Evaluation and Planning, 2030)
Brazil	2008	Expert panel	Government agency	Estudos Prospectivo: Cadeia Coureiro, Calçadista e Artefatos [Prospective Studies: Chain leather, Footwear and Artifacts]
Brazil	2008	Expert panel	Government agency	Cadeias e móveis [Chairs and Furniture]
Brazil	2008	Expert panel	Government agency	Estudos prospectivos: Aeronáutica [Prospective studies: Aerospace]
Brazil	2008	Expert panel	Government agency	Estudos prospectivos: Plástico [Prospecfive studies: Plastic]
Brazil	2008	Expert panel	Government agency	Estudos prospectivos: Equipamentos médicos, hospitalares e odontológicos [Prospective studies: Medical Equipment, Hospital and Dental]
Brazil	2009	Expert panel	Government agency	Estudos prospectivos: Higiene pessoal, perfumaria e cosméticos [Prospective studies: Personal Hygiene, Perfumery and Cosmetics]
Brazil	2010	Expert panel	Think tank	Energia solar fotovoltaica no Brasil: subsídios para tomada de decisão [Photovoltaic solar energy in Brazil: support for decision making]

Country	*Year*	*Exercise type*	*Lead author type*	*Title*
Brazil	2010	Expert panel	Think tank	Eletrônica Organânica: contexto e proposta de ação para o Brasil [Organic Electronics: context and proposed actions for Brazil]
Brazil	2010	Expert panel	Government agency	Estudo Prospectivo Setorial: Têxtil e Confecção [Prospective Study Sector: Textile and Garment]

Printed in Austria
V.13-83218—May 2013

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