Manufacturing

Background paper for the European Commission's High Level Group on Key Technologies for Europe

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Abbreviations

API	Application Programming Interfaces
CEEC	Central and East European Countries
CIP	Competitive Industrial Performance
EC	European Commission
EI	Enterprises integration
ERA	European Research Area
ERM	Integrated Enterprise Resource Management
ETP	European Technology Platform
EU	European Union
EU-15	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom
EU-25	EU-15 plus Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia
GDP	Gross domestic product
GNP	Gross national product
HT	High-technology
ICT	Information and communications technologies
IPPD	Integrated Product and Process Development
IPR	Intellectual property rights
IT	Information technology
KI-SME	Knowledge-intensive SMEs
LT	Low-technology
MHT	Medium- high-technology
MNC	Multinational corporation
MNE	Multinational entreprise
MT	Medium-technology
MVA	Manufacturing value added
M&S	Modelling and simulation
NAS	New accession states
OECD	Organisation for Economic Co-operation and Development
PPS	Purchasing Power Standard
RB	Resource-based
R&D	Research and development
RTD	Research, technological development
RTD&I	Research, technological development and innovation
SME	Small and medium-sized enterprises
SRA	Strategic research agendas
SWOT	Strengths, weaknesses, opportunities and threats
S&T	Science and technology
WTO	World Trade Organization

Executive Summary

This report addresses the challenges and opportunities for Europe in the domain of Manufacturing towards strengthening the European Research Area (ERA). European manufacturing has great potential as part of a sustainable EU economy, but its success will depend upon continuous innovation in products and processes.

The report addresses the socio-economic challenges for Europe, analyses Europe's science and technology base and activities in Manufacturing, the major challenges is facing, its strength, weaknesses, opportunities and threats (SWOT) and provides an overview of key aspects and trends of research and development (R&D) in Manufacturing for the next 10-15 years.

European manufacturing industry has been, and continues to be, successful in maintaining its leadership. However, this position is menaced on two fronts. On the one hand, EU industry faces continuing competition from the other developed economies, particularly in the high-technology sector. On the other, low-wage economies are increasingly threatening the more traditional manufacturing sectors. While the pursuit of new production paradigms might involve significant disruption, failure to break the current pattern gives rise to equally serious threats for European industry:

The seven challenges that lie at the heart of the near future of manufacturing in this increasingly complex and globalize environment are: increasingly competitive global economic climate; anticipate new market and societal needs; rapid advances in science and technology; increase supply chain efficiency; environmental challenges and sustainability requirements; integrate new knowledge and improve workforce skills; and, societal values and public acceptance of technology. These challenges will influence research trends in manufacturing over the next 10 to 15 years.

To attain this challenges manufacturing enterprises have to progress towards: customer-responsive enterprises, totally connected, reconfigurable and efficient, based on knowledge and technology innovation and, environmental sustainability.

The context in which manufacturing corporations work in the future will depend even more on flexibility and speed, as well as on localised production. Manufacturing is also likely to become increasingly service intensive. The basis of competition will be creativity and innovation in all aspects of the manufacturing corporation. New technologies and new business practices will be inseparable.

Many of manufacturing research needed to attain these challenges are crosscutting areas, that is, they are applicable to several enabling technologies. It is wise to establish an interdisciplinary manufacturing research and development program that emphasizes multi-investigator consortia both within institutions and across institutional boundaries; to focus long-term manufacturing research on developing capabilities in the enabling technologies to meet the challenges, with an emphasis on crosscutting technologies. Adaptable and reconfigurable manufacturing systems, information and communication technologies, and modelling and simulation are three key enabling technologies research areas that address several manufacturing challenges. Two important breakthrough technologies—submicron manufacturing and enterprise simulation and modelling—will accelerate progress in addressing the manufacturing challenges.

The next generation of advanced manufacturing and processing technologies will be expensive to produce, and no one entity has all the resources and expertise needed. Cooperative R&D share costs, risks, and expertise is necessary.

1. Introduction

In broad terms *Manufacturing* is defined as the processes and entities required to create, develop, support, and deliver products. Manufacturing sells goods to other sectors in the economy and, in turn, buys products and services from them. Manufacturing spurs demand for everything from raw materials to intermediate components to software to financial, legal, health, accounting, transportation, and other services in the course of doing business.

Nowadays, technology assumes a central role in human development. Many human needs are met through its application. Technology is used to make things, it is found in products in material form, and, in the asset we call ‘know how’. It contributes to our expectations about life-style and patterns of consumption. Indeed, the conditions that lead to our present [unsustainable] culture of consumption are strongly influenced by technologies that support modern information and communications, materials, nano- and bio-technologies, energy and environment. Manufacturing is the backbone of our technology.

Manufacturing systems have considerable economic, social and environmental significance. Presently, manufacturing contributes to almost 20% of European gross value added, employs around 18% of the European workforce and contributes about 25% of the waste, 23% green house gases and 26% of NO_x generated in Europe[1].

European industry with its 40 million workers is the engine of the economy and has demonstrated the capacity progressively to decrease its environmental impact, following adequate research, technology development and innovation (RTD&I) efforts. A healthy manufacturing sector is critical for other reasons as well – innovation and productivity. Innovation holds the key to rising productivity, and productivity gains are the key to both economic growth and a rising standard of living.”[2]

European manufacturing has great potential as part of a sustainable European Union (EU) economy, but its success will depend upon continuous innovation in products and processes. In addition to demanding increased commitment from the private sector, it is essential to combine European Commission (EC) efforts with those of Member States to develop a common vision regarding RTD&I – starting at the industrial level but going much further in addressing technical, environmental and social issues[2].

Manufacturing has changed radically over the course of the last 25 years and rapid changes are certain to continue. The emergence of new manufacturing technologies, spurred by intense competition, will lead to dramatically new products, and processes. New management and labour practices, and organizational structures and decision-making methods will also emerge as complements to new products and processes. Many forces—social, political, and economic, as well as technological—will shape the manufacturing environment in 2020[3].

A critical step in preparing for the future will be the development of an underlying technical foundation through research by industry, academia, and government institutions, which must be guided by a clear vision of manufacturing in next decades and an understanding of the fundamental challenges that must be met to realize this vision.

The present report is a contribution to the High Level Expert Group on “Key Technologies for Europe” set by the European Commission, Directorate-General for research, Directorate K (“Knowledge-based economy and society”), Unit K2 (“Science & Technology Foresight”), focusing on “Manufacturing”. The aim of this High Level Expert Group is to produce a report on emerging science and technology trends in fifteen broad research domains based on the individual expert’s report for each of these domains.

The report on Manufacturing synthesises significant manufacturing challenges, opportunities, threats and weakness that can guide current and future EU investments in research, based on recent visionary and foresight studies. It is not intended to be a new study or contribution, impossible to carry out within the short time frame of the mandate of the High Level Expert Group. The report starts analysing the socio-economic challenges for Europe in terms of manufacturing, followed by a global perspective of the potential and emerging scientific and technological research in manufacturing. Based on this analysis, strength, weakness, opportunities and threats of Europe's manufacturing sector and related enterprises are enunciated and a general outlook on futures perspectives for Manufacturing RTD&I over next 10-15 year established. This report does not intend to provide a list of critical industries or technologies or sciences that will condition the future of manufacturing, or exhaustive list of high potential specific topics of research. Instead, it outlines some key areas that lie at the core of the predicted evolution of manufacturing in a holistic perspective but that can be applied across the whole sphere of Manufacturing in a synergetic manner. Other technological and scientific areas relevant to Manufacturing will be addressed in other background reports of the High-Level Group. Therefore, this report do not address the specific developments in new emerging themes (Cognitive, Complexity and Services), or in converging technologies (materials (nano-) technologies, biotechnology, information, social sciences), or systemic transition areas (environment, energy) as these will be addressed elsewhere.

2. The Socio-economic challenges for Europe regarding manufacturing

2.1 Manufacturing scope

Traditionally, manufacturing has been defined as the transformation of raw materials into useful goods. However it can be broadened to the general transformation of all resources to meet human needs[4]. Manufacturing encompasses the development, design, production, delivery, and support of products. In the course of this study, it became increasingly clear that the scope of manufacturing will become even broader in the future as new configurations for the manufacturing enterprise emerge and the distinctions between manufacturing and service industries become blurred[3].

Nowadays, manufacturing is an integral part of a web of inter-industry relationships that create a stronger economy. Manufacturing sells goods to other sectors in the economy and, in turn, buys products and services from them. Manufacturing spurs demand for everything from raw materials to intermediate components to software to financial, legal, health, accounting, transportation, and other services in the course of doing business[5].

The complexity of actual manufacturing sector with interdependences among sectors makes manufacturing a highly complex system difficult to analyse in all its constituents. Figure 2.1 suggests a top-level view of a possible manufacturing taxonomy, identifying and interrelating the principal functions and types of processes, equipments, materials, and activities intrinsic to making any kind of product[6].

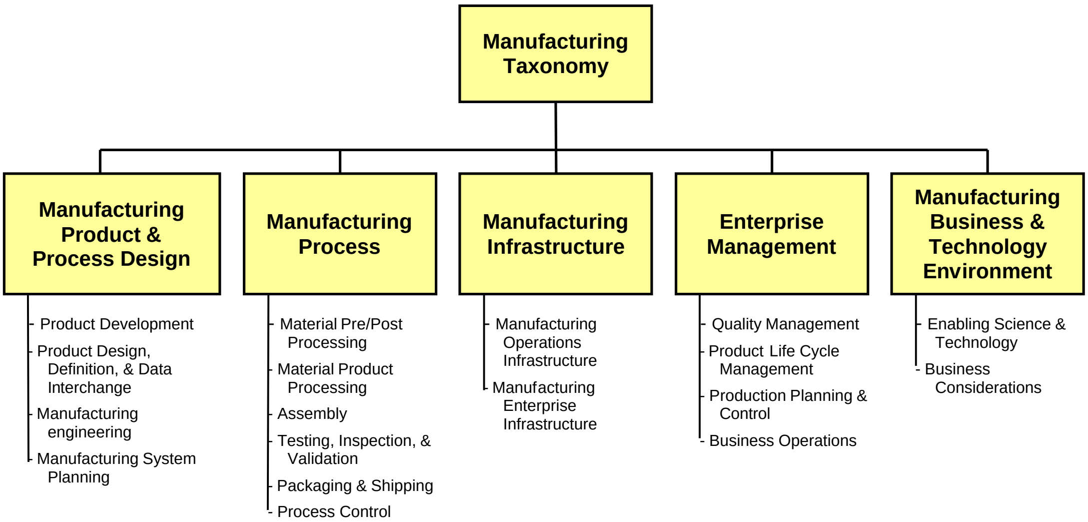


Figure 2.1 - The top-level Taxonomy structure provides a functional framework for integration of manufacturing information across different domains[6]

This top-level structure has five major elements that provide a generic framework under which various types of manufacturing information can be organized, namely

1. *Manufacturing Product & Process Design* – Encompasses all of the functions and processes associated with conceiving and developing new (and improved) products and manufacturing processes, to the point of readiness for manufacturing execution.
2. *Manufacturing Processes* – Encompasses all of the functions associated with translating product designs into finished goods.

3. *Manufacturing Infrastructure* – Encompasses all of the functions that support the creation of product, both directly and indirectly.
4. *Enterprise Management* – Encompasses all of the functions associated with managing the operation of a manufacturing business entity.
5. *Manufacturing Business & Technology Environment* – Encompasses all of the issues and functions not addressed under the other four elements.

Each of these Taxonomy elements can be expanded to a fairly detail level. However, for the analysis made in this report this top-level structure is sufficient. For details see reference [6].

2.2 Socio-economic SWOT analysis of manufacturing

The general contribution trend to global output shares of world manufacturing output by civilization or country in the last centuries (1750-2000) is depicted in Figure 2.2.

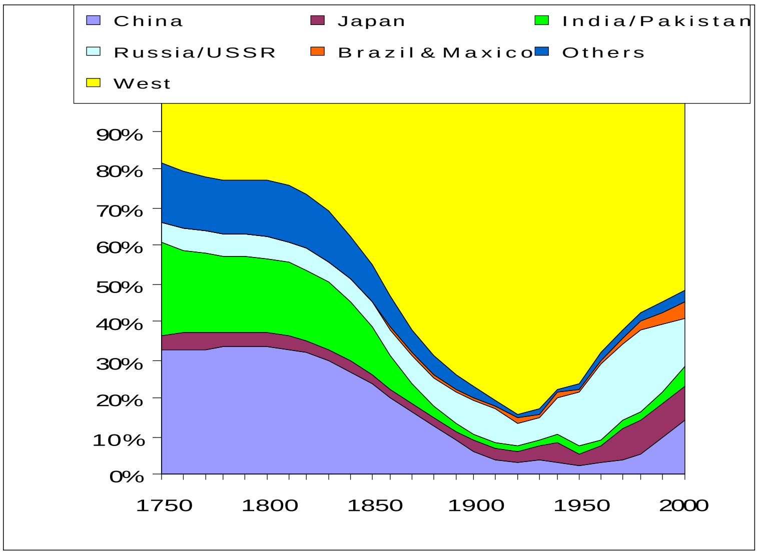


Figure 2.2 - Contribution to global output shares of world manufacturing output by civilization or country in the last centuries (1750-2000) Source:Mitchell Tseng, CIRP

Productive activities in general become more and more knowledge-based, service-oriented and network-based; services sectors and traditional industrial sectors are in this respect equally important as high tech ones as they employ a large proportion of Europe's workforce. Nowadays, the socio-economic impact of manufacturing is tremendous (see Box 2.1).

Box 2.1 - Manufacturing in Europe[7]

SOME DATA ABOUT MANUFACTURING IN EUROPE

- Turnover ~4,300 million Euro
- Added value 1,600 million Euro
- Jobs 40 million (directly)
- 80 million (through services)

SOME PRINCIPAL SECTORS	*Production*	*Jobs*
• Motor vehicles	480 million Euro	2.5 million
• Machinery	320 million Euro	2.0 million
• Aerospace	60 million Euro	0.5 million

EXPORT-IMPORT INDUSTRY SPECIALIZATION

- Traditional Industry + +
- Scale Intensive Industry –

• Special Supplier Industry	+
• Science Based Industry	–

The worldwide produced "portfolio" by the advanced regions is shown in Figure 2.3.

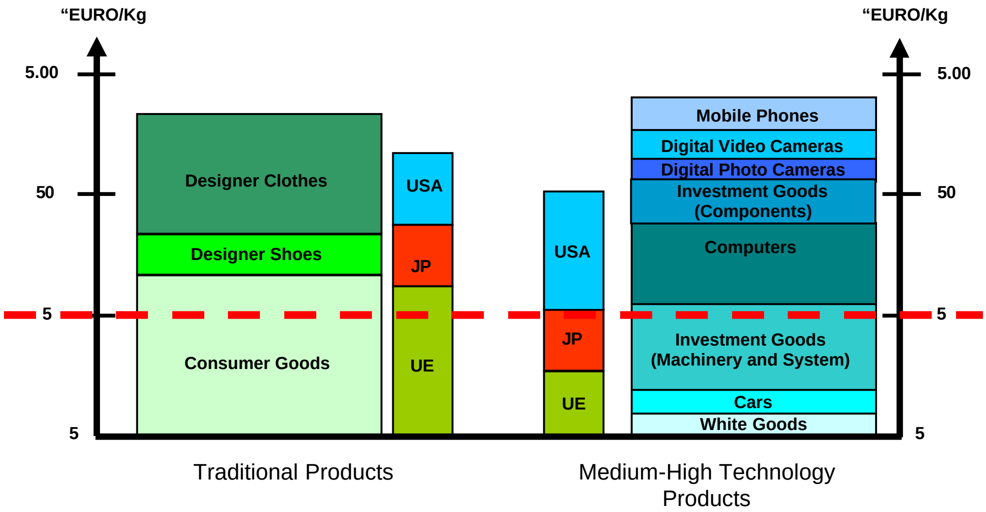


Figure 2.3 - The worldwide produced "portfolio" by the advanced regions[7]

Table 2.1 shows the manufacturing world market share during the past years.

	1997	1998	1999	2000	2001
Total Import (millions of Euro)	3.581.045	3.651.262	3.792.144	4.162.171	4.053.029
World Market Shares					
EU	39,1	40,6	38,9	36,1	37,3
USA	12,4	12,1	12,0	12,1	11,3
China	8,1	8,0	8,7	9,7	10,1
Japan	8,4	7,5	7,7	8,2	7,4

Table 2.1 - The manufacturing world market share during the past years[7]

A detailed socio-economic analysis of strengths, weaknesses, opportunities and threats (SWOT) of manufacturing industry is given in Appendix 1. Here, for the sake of brevity the SWOT analysis is summarized in Table 2.2.

2.3 Socio-economic challenges to EU manufacturing

The most urgent issue facing Europe today is the lack of growth and job creation that safeguards the standard of living and social protection Europeans have grown used to.

In the last decade, Europe's growth and productivity has failed to match its major economic partners. Emerging economies, social and political transitions, and new ways of doing business are changing the world dramatically. These trends suggest that the competitive environment for manufacturing enterprises in future will be significantly different than it is today. To be successful in this competitive climate, future manufacturing enterprises will require significantly improved capabilities. The attainment of these capabilities represents the challenge facing manufacturing[3].

Table 2.2 – SWOT analysis of manufacturing

Strengths	Weaknesses
- Europe is persistently a world leader in terms of quality of life and social cohesion - Some European countries are ranked above the US in terms of knowledge society composite performance indicators - European manufacturing industry has been, and continues to be, successful in maintaining its leadership - European industry is modern and competitive in many respects - A long lasting industrial culture exists in EU - Europe has taken on board the sustainable development dimension - Leading-edge research capabilities are available across Member States - European enterprises is that the majority are SMEs giving flexibility and innovative character - Historic and cultural differences between individual Member States and regions bring a diversity of viewpoints and skills - EU still one of the largest manufacturing exporters - Some EU countries have a long established exporters record - Some EU countries have a rapid technological upgrading - HT production in MVA rose - MT products dominates world exports - EU strength is concentrated in medium- and high-technology sectors	- Productivity growth in European manufacturing industry as a whole has been below US levels in recent years - EU Innovation activity is too weak - EU tends to specialise in medium- to high technology and mature capital-intensive industries - Structural problems in the European economy remain - EU high-level education system is currently under-performing the US and Japan - European enterprises is that the majority are SMEs leading to smaller export impacts - EU exports share has gradually been decreasing in the past decades - Less-skilled production moved to lower-wage countries leaving EU - EU countries have a very large disparity in manufacturing capabilities and exports weakening EU position on the market - Some EU countries have a relatively low per capita export values showing weaknesses in their manufacturing sector - Some EU countries stagnated in terms of technological upgrading - Medium-technology products are not the main drive of growth - High % of high-technology products come from developing countries - Raw-based and low-technology products exports slowed down significantly in rich countries
Opportunities	**Threats**
- Leading-edge research capabilities are available across EU Member States that gives place to innovation - Science, technology and innovation are becoming increasingly global - A significant investment in research would help to sustain not only competitiveness but also employment - Industrial actors need to make further efforts to increase their investments in research to guarantee sustainable competitiveness - Historic and cultural differences between individual Member States and regions bring a diversity of viewpoints and skills necessary to innovation - The majority of European enterprises are SMEs giving flexibility and innovative character to them - High-technology products are the fastest-growing sector - Some East European countries that joined EU are entering the high-technology manufacturing being an opportunity to innovation in the sector - The engineering in the medium-technology group has the most dynamic products - Medium- high- manufacturing sector will be the drive of growth worldwide - Lower-wages countries import machinery, raw	- Industrialized countries are loosing global manufacturing market and exports - EU industry are not investing enough in research to guarantee sustainable competitiveness - EU industry faces continuing competition from the other developed economies - Asia is becoming an increasingly potent force in the marketplace - China industrial sector has increased its dominance over time - Developing countries built considerable domestic high-technology - Low-wage economies are increasingly threatening the more traditional manufacturing sectors. Competition with low-wage countries in labour-intensive, mass-consumption products will be more and more difficult for EU manufacturers - Employment share of EU industry decrease - New production paradigms might involve significant disruption, failure to break the current pattern gives rise to equally serious threats for European industry - Medium-technology products world exports decrease - China highest share is in MHT products - Possible formation of China and India common

materials and components to produce the goods	market

There is a need for the development and implementation of a European manufacturing strategy based on research and innovation which would promote industrial transformation, secure and create high added value employment and ensure the maximum possible share of world manufacturing output.

The vision for this change cannot be framed from a single perspective, nor realised through narrow, highly specialised approaches. Instead, an integrated knowledge community embracing a broad swathe of manufacturing interests, and including as many actors and stakeholders as possible – from Europe and beyond must address this task, as MANU*FUTURE* has been doing. Given the diversity of needs and the varying levels of economic development currently existing in nations across the enlarged EU, no single solution can meet all cases. Rather, the intention is to define broad strategic concepts leading to ideas that can be applied, shared and adapted across countries, regions and industries. Environmental and social targets will dictate new paradigms that reflect the long-term needs for a more sustainable way of manufacturing and a new knowledge based work culture.

The preliminary MANU*FUTURE study*[2], conclude that:

- *An economy based on service industries alone will not survive in the longer term*. Growing numbers of jobs in manufacturing related services and in the service sector in general have been compensating for the loss in direct manufacturing employment. However, the EU industry is currently under significant competitive pressures from developed and low-wage economies alike. As each job in manufacturing is linked to two jobs in services, the reliance on services cannot continue in the long term without a competitive EU manufacturing sector.

- *Industrial transformation is a must.* In order to meet the competitive, environmental and social challenges, a concerted effort will be needed to transform European manufacturing from a resource intensive to a knowledge intensive, innovative sector capable of achieving and maintaining technological and production leadership in the global market place.

- *New approach to manufacturing is required – innovating production.* The traditional structure of manufacturing industries is constructed upon the three pillars of *land*, *labour* and *capital*. The challenge is to move towards a new structure, which can be described as 'innovating production', founded on *knowledge* and *capital*. The transition will depend on adoption of new attitudes towards the continued acquisition, deployment, protection and funding of new knowledge.

- *A competitive R & D system is created by multiple factors.* The knowledge driven economy demands a competitive R&D system, which is facilitated by favourable framework conditions, a new approach to knowledge generation and innovation, adaptation of education and training schemes, creation of easily accessible research, technological development and innovation (RTD&I) infrastructures and finding solutions meeting new societal needs and the demands of an increasingly ageing public.

Tomorrow's solutions will be holistic, identifying multiple perspectives and linkages between novel approaches to customisation, customer response, logistics and maintenance. A broader definition of the term 'manufacturing' will encompass an integrated system that includes the whole cycle of creation, production, distribution and end-of-life treatment of goods and product/services, realising a customer/user driven innovation system. (*It can be estimated that up to 80% of innovations are driven by customer requirements.*)

The basis for competition will be creativity and innovation because (1) the manufacturing context will be broader and (2) social and organizational structures will be much more knowledge-based, dynamic, fluid, and globally distributed. Manufacturing enterprises will plan, create, and manage new products, processes, supply chain systems, and other business aspects of the enterprise (e.g., finance and marketing) concurrently.

The current typically linear approach to research, development, design, construction and assembly will be replaced by simultaneous activity in all areas to satisfying global demand and shorten time-to-market. Special emphasis will also be put on embedding information and communications technologies (ICT) within other techno-organisational developments, as this is perceived to be crucial in the development of the knowledge base and networked enterprises.

2.4 EU policy response

EC Framework Programmes play a unique, direct and also catalytic role in stimulating and structuring research in Europe. It offers increased visibility and helps to create the critical mass necessary to address a range of research challenges and it gives new dimension towards national or regional activities. Figure 2.4 summarizes the road to Europe's future in industrial technologies.

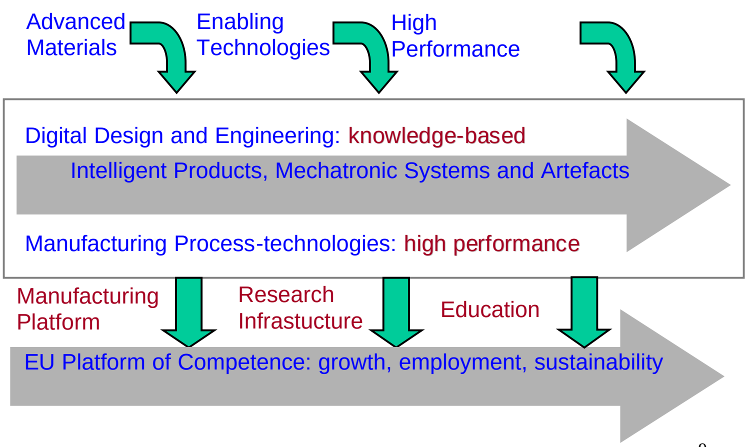


Figure 2.4 - The road to Europe's future in industrial technologies[9]

In addition, the need to create better synergy between European and national investments and between public and private efforts towards the definition of RTD priorities, timeframes and budgets on a number of strategic issues with high societal relevance EC recently established European Technology Platforms (ETPs)[10] as key component of future European research policy with the specific aim on the definition of a Strategic Research Agenda (SRA) based on a strategic vision from the leading companies in the sector, and the mobilization of the necessary critical mass of research and innovation effort to implement it[11]. To guarantee the success of these ETPs industry is strongly involved in setting them up, taking the lead and driving them forward. They unite all relevant actors – industry, the research community and public authorities as well as the financial community, regulators, users and consumers and wider civil society – in addressing a particular technological challenge. They can ensure that Europe develops coherent and effective programmes and actions across a wide range of policies oriented towards tackling key technological challenges. ETPs are playing a key role in the preparations for the EU Seventh Framework Programme (FP7).

ETPs enable principal stakeholders – industry, research organisations, Member State governments, the European Parliament and the Commission – to develop a long term vision of the challenges in a specific technology area and create a coherent strategy to address these.

At the heart of the approach is the development of industry-led strategic research agendas to implement action plans through long-term public-private partnerships. Technology platforms are neither owned nor led by the Commission but driven by the stakeholders who come together to set up the platform – the primary value is for the stakeholders. The role of the Commission is to encourage and guide the stakeholders.

Some 22 technology platforms have been established to date covering: new technologies – such as nanoelectronics; development of technology breakthroughs to keep high-technology sectors, such as aeronautics and air transports, at the leading edge; renewal or restructuring of traditional industries, including construction, steel making, and textiles and clothing; new technologies for sustainable development – such as sustainable chemistry; and new technology-based goods or services – such as mobile communications.

In parallel with the individual platforms EC promoted the development of a general initiative on the future of manufacturing – MANU*FUTURE* – to provide support across the whole of European industry since a strong manufacturing base is vital to the Lisbon strategy to make the EU the world's strongest knowledge-based economy.

Discussions on MANU*FUTURE* started in early 2003 with an initial vision document presented in Milan in December 2003, followed by a public consultation exercise. A series of workshops were held around Europe in mid 2004, culminating in a revised vision document [2] presented in the Netherlands in December 2004. At the end of this exercise representatives of four major stakeholders confirmed their support to create an ETP on manufacturing, MANU*FUTURE* platform that is already working. An SRA is now being developed by the main stakeholders.

Synergies between ETPs and MANU*FUTURE* platform are clearly existent, Figure 2.5. Sectoral ETPs can contribute to the overall MANU*FUTURE* vision, but that a horizontal manufacturing platform is necessary to create a broad knowledge-sharing community. This would permit more effective support for total processes by ensuring that knowledge and innovation generated at an early stage in business-to-business supply chains becomes more visible to the downstream partners. It would also make possible a more effective coordination of sectoral strategies and orchestration of the use of strategic resources. Thus MANU*FUTURE* has more an 'umbrella' nature than that of other ETPs, integrating all stakeholders and their needs. Its main role is to govern research, technological development and innovation (RTD&I) efforts aimed at the transformation of the European manufacturing industry at two levels: a policy level aimed at continuous development of the MANU*FUTURE* vision and promotion of the Lisbon objectives; and an operational level employing a technological approach exploiting all possible synergies arising from the converging nature of science and technologies and addressing common problems or bottlenecks faced by the sectoral platforms currently in operation or under development.

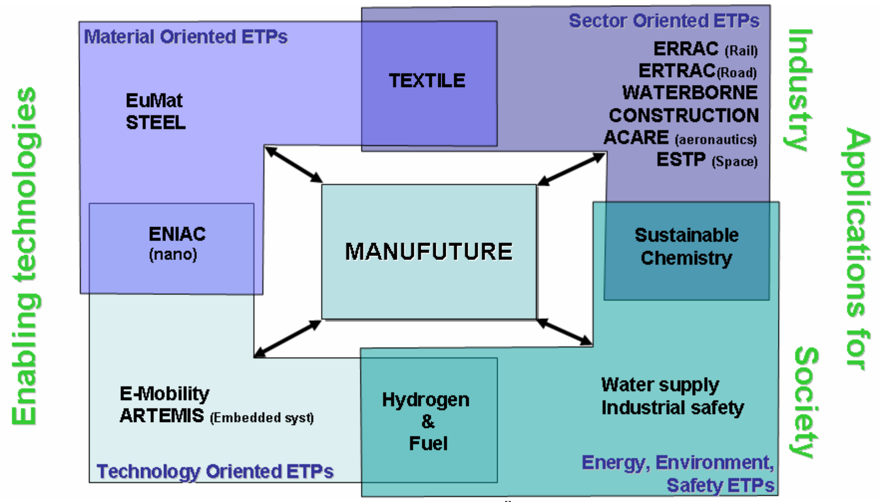
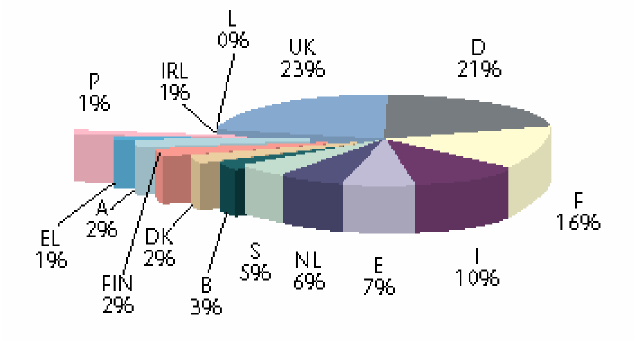


Figure 2.5 – MANU*FUTURE* platform links to other ETPs[9]

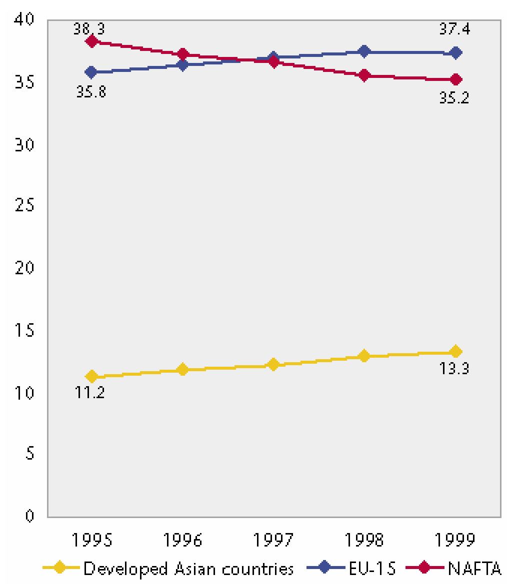
3. Europe's science and technology base and activities in Manufacturing

Research is proving to be a central component of the new economy and knowledge-based society developing worldwide. More than ever before, it is one of the basic driving forces behind economic and social progress, and a key factor in business competitiveness, employment and the quality of life. Citizens are becoming more and more aware of the impact of science and technology on their daily lives. Enterprises appreciate the growing importance of research and new technologies for their competitiveness. Science and technology are also central to the policy-making process. Policy makers are now accepting that measures to stimulate research and the exploitation of knowledge must play a more central role in government policies. When applied efficiently the resources used in research are directly related with the development and progress of society.

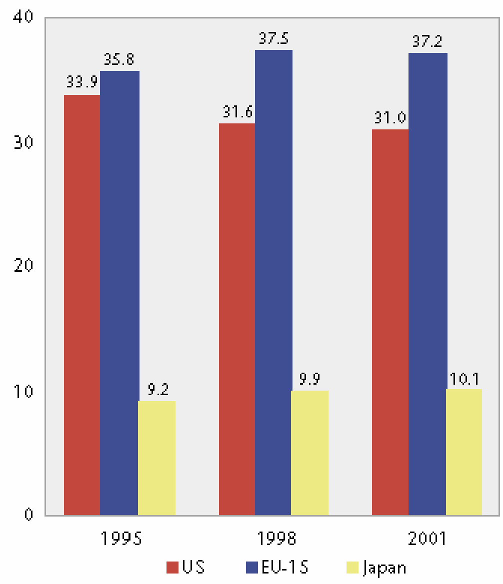
The performance of science can be measured by a number of different indicators but the most common ones are publications and related citations and patents. Although the picture across wider Europe is diverse (Figure 3.1), the EU-15 is now the best performing world region in terms of number of publications (Figures 3.2 and 3.3). In terms of numbers of publications as well as world share, the EU-15 have gained in the latter half of the 1990s, and surpassed NAFTA in 1997 (Figures 3.2).



Source: DG Research
Data: ISI, CWTS (treatments)
Note: Scientific contribution takes only into account the publications that involve at least one EU-15 country.
The number of these publications make the EU-15 total here and the shares by EU-15 country is then calculated.
Figure 3.1 Scientific contribution by EU-15 Member States (1995-1999) [12]



Source: DG Research
Data: ISI, CWTS (treatments)
Figure 3.2 Publication shares (%) by EU-15, NAFTA, and Developed Asian countries (1995-1999) [12]



Source: DG Research
Data: ISI, CWTS (treatments)
Figure Figure 3.3 Publication shares (%) by EU-15, US, Japan (1995, 1998, 2001) [12]

Patents represent an outcome of technologically oriented inventive activity. They represent an important source of data which can help to shed light on patterns of technological change. Tables 3.1 and 3.2 show the share of European and US patents by technology field, % (1999), respectively.

Countries/Groups	Electricity	Instruments	Chemistry	Processes	Mechanics	Consumer goods	All fields
European Union	36.3	36.5	37.5	50.0	54.1	55.7	42.6
Belgium	0.6	1.0	1.6	1.5	0.7	1.0	1.1
Denmark	0.4	0.7	1.1	1.1	0.8	1.1	0.8
Germany	13.7	14.5	14.8	20.2	27.6	21.3	17.6
Spain	0.3	0.5	0.6	0.9	0.7	1.5	0.6
France	5.6	5.5	5.6	6.3	8.1	8.9	6.3
Italy	1.8	2.2	2.5	4.6	3.9	5.8	3.0
Netherlands	3.3	2.0	2.1	3.1	1.5	2.7	2.5
Austria	0.5	0.6	0.6	1.3	1.5	2.0	0.9
Finland	2.1	0.7	0.7	1.9	0.8	1.0	1.2
Sweden	3.1	2.7	1.3	3.1	3.2	2.9	2.6
UK	4.7	5.8	6.4	5.7	5.0	6.8	5.6
US	35.2	39.7	39.9	27.1	22.1	23.5	33.1
Japan	20.5	13.6	13.1	12.4	13.8	5.6	14.4
World	100	100	100	100	100	100	100

Source: DG Research
Data: EPO; processed by OST

Table 3.1 Share of European patents by technology field, % (1999) [12]

Countries/Groups	Electricity	Instruments	Chemistry	Processes	Mechanics	Consumer goods	All fields
European Union	10.7	13.8	23.7	20.9	20.8	12.1	16.4
Belgium	0.2	0.6	1.2	0.7	0.3	0.2	0.5
Denmark	0.1	0.2	0.8	0.4	0.3	0.2	0.3
Germany	3.3	5.1	8.5	8.9	10.9	3.9	6.3
Spain	0.1	0.1	0.3	0.3	0.2	0.3	0.2
France	2.0	2.2	4.1	2.6	3.0	2.0	2.7
Italy	0.7	0.7	1.5	1.8	1.2	1.2	1.1
Netherlands	0.9	0.9	1.2	1.1	0.4	0.5	0.9
Austria	0.1	0.2	0.5	0.6	0.4	0.5	0.3
Finland	0.5	0.3	0.3	0.8	0.4	0.3	0.4
Sweden	0.7	0.9	0.8	1.1	1.2	0.7	0.9
UK	1.9	2.5	4.2	2.5	2.3	2.1	2.6
US	50.9	55.4	52.7	53.7	50.7	66.6	53.7
Japan	27.8	23.0	15.0	16.2	19.1	7.0	20.1
World	100	100	100	100	100	100	100

Source: DG Research
Data: EPO; processed by OST

Table 3.2 Share of US patents by technology field, % (1999) [12]

Table 3.3 summarizes the growth in shares of patents at the European and US patent offices %. These figures allows us to conclude that science and technology development and innovation in Europe has a positive trend but needs to be improved to outperform the main competitors.

	European Patents					
	European Union		United States		Japan	
	1992-1995	1996-1999	1992-1995	1996-1999	1992-1995	1996-1999
All fields	-0.8	-0.3	4.2	-0.5	-6.3	-1.5
Electricity	0.3	1.8	4.0	-1.7	-6.9	-2.7
Instruments	-1.9	0.1	6.0	-0.6	-7.5	-4.1
Chemistry	-0.7	-1.1	3.3	0.3	-6.2	-2.6
Processes	-0.8	-0.5	3.8	-0.1	-3.7	-0.5
Mechanics	-0.7	0.2	3.9	-2.6	-6.3	2.5
Consumer Goods	-0.9	-1.5	3.1	1.9	-4.0	-3.1
	US Patents					
	European Union		United States		Japan	
	1992-1995	1996-1999	1992-1995	1996-1999	1992-1995	1996-1999
All fields	-4.5	0.1	1.2	-0.5	-0.3	-1.6
Electricity	-7.2	-0.9	0.8	0.9	-0.2	-4.4
Instruments	-3.9	0.3	2.1	-0.9	-2.9	-0.2
Chemistry	-2.7	0.9	1.1	0.7	-0.4	-6.0
Processes	-3.2	0.5	0.8	-0.9	1.0	0.5
Mechanics	-3.0	2.3	2.4	-2.5	-4.9	3.0
Consumer Goods	-6.7	1.4	0.9	-1.0	-1.9	-0.6

Table 3.3 Growth in shares of patents at the European and US patent offices % [12]

3.1 Global R&D spending

A simple analysis of the world research investment shows EU is clearly behind its main competitor in the worldwide scene. Figure 3.4 shows the R&D expenditures (all sectors) of the European Union, Japan and US in constant 1995 Purchasing Power Standard (PPS) between 1990 and 2003. From this Figure it is clear the EU gap in relation to the other leading world economies.

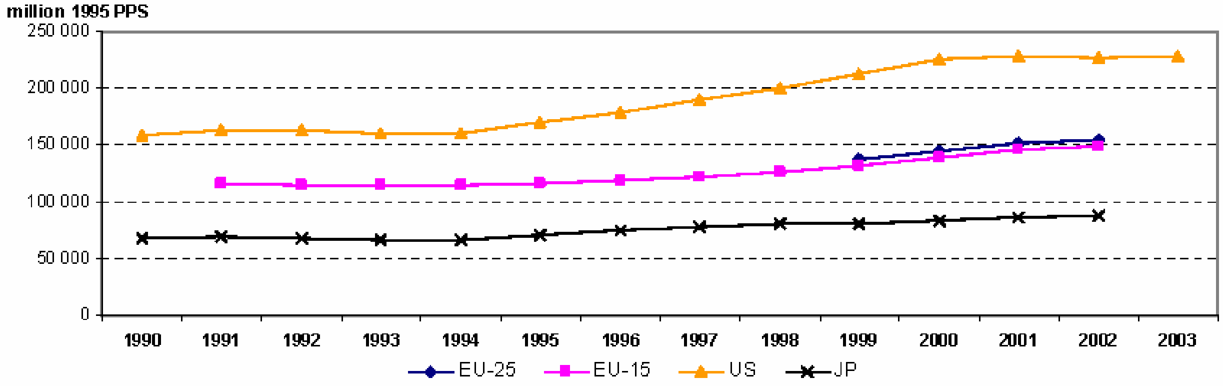
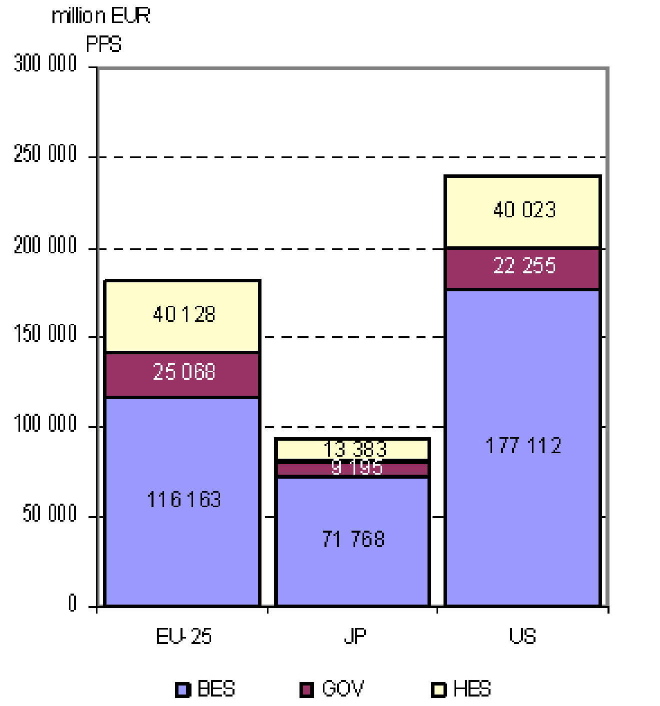


Figure 3.4 - R&D expenditure in million constant 1995 PPS in the EU-25, Japan and the United States from 1990 to 2002

If we also look into the structure of the expenditures between public and private sectors (Figure 3.5), we find that enterprises in Europe are clearly not investing enough in research. This raises many potential problems linked to the sustainable competitiveness of the European manufacturing sector in an increasingly complex and globalized environment. Industrial participants need to make further efforts to increase their investments in research, following the trend acknowledge during the past 10 years by the OECD. A significant investment in research would help to sustain not only competitiveness but also employment – as evidenced by the Netherlands where, between 1994 and 1998, 8% of fast-growing firms created 60% of employment growth[13].



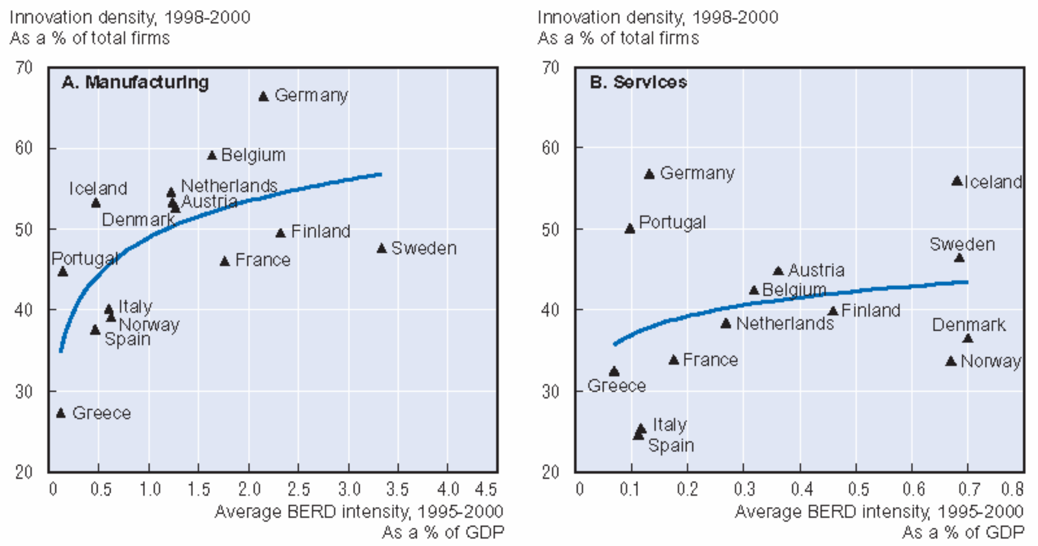
HES – Higher Education Sector (Top of chart), GOV – Government Sector,
BES – Business Enterprise Sector (Bottom of chart)

Figure 3.5 - R&D expenditures (2002) in PPS by institutional sector in the EU-25, Japan and the United States

The trend in Figure 3.4 shows clearly why, in the Barcelona European Council, the heads of state set an objective to increase research investment to 3% of GDP by 2010, in order to bridge the gap with the other regions. Apart of proposing to redirect public spending towards research and innovation, the "3% action plan" places the onus mainly on the business sector, and especially on the manufacturers. It implies also progressing jointly, improving public support to research and innovation as well as framework conditions for private investment in research. Public money is increasingly aimed at scientific and technological fields believed to have great economic and societal value, in particular, ICT, biotechnology and nanotechnology. Several countries, including Denmark, Germany, the Netherlands and Norway have created special funds to finance research in priority fields.

Regardless of the long-held view of services as slow-changing, recent survey results illustrate great potential for innovation in service sector firms. The share of innovative firms in the service sector remains lower than that in manufacturing (Figure 3.6), but innovation rates in financial intermediation and business service firms (more than 50% and 60%, respectively) exceed the manufacturing average.

Growth rates for R&D in services outpace those in manufacturing by a sizeable margin. While large service sector firms tend to be more innovative than smaller ones overall, small firms in the business services and financial intermediation sectors are more innovative than those in other service industries.



Source: OECD, based on data from Eurostat, CIS3 survey and ANBERD database, 2004.

Figure 3.6 - Business R&D intensity and innovative density by country and sector (BERD as a % of value added in industry and innovative density as a % of all firms) [14]

In recent years, weak economic conditions limited investments in science and technology. Global investments in R&D, for example, grew at a rate of less than 1% between 2001 and 2002, compared to 4.6% annually between 1994 and 2001. As a result R&D spending slipped from 2.28% to 2.26% of GDP across the OECD, driven by declines in the United States, which was hard hit by the economic downturn. R&D intensity also declined in several Eastern European countries that are continuing to restructure their economies, but it increased in the EU25 as a whole, as well as in Japan and the Asia-Pacific region.

Recognising the importance of innovation to economic growth and performance, most OECD governments aimed to shield public R&D investments from spending cutbacks and, in many cases, were able to increase them modestly. Although they remain far below levels of the early 1990s, OECD-wide government expenditures for R&D rose from 0.63% to 0.68% of GDP between 2000 and 2002 as budget appropriations grew, most notably in the United States, followed by Japan and the EU. Reflecting growing concerns about national security, much of the US increase related to defence R&D, although health-related R&D expenditures also increased.

Driving recent reductions in OECD-wide R&D intensity were steep cutbacks in R&D in the US business sector. Industry-financed R&D declined from 1.88% to 1.65% of GDP in the United States between 2000 and 2003, while R&D performed by the business sector declined from 2.04% to 1.81% of GDP. Japan, in contrast, saw a steep increase in business-performed R&D – from 2.12% to 2.32% of GDP between 2000 and 2002 – and modest gains were posted in the EU.

Science, technology and innovation are becoming increasingly global. The combined R&D expenditures of China, Israel and Russia were equivalent to 15% of those of OECD countries in 2001, up from 6.4% in 1995. Within many OECD countries, the share of R&D performed by foreign affiliates of multinational enterprises (MNEs) has also increased. Globalisation has been fuelled largely by the activities of foreign affiliates of large MNEs. The global reach of MNEs is expanding as non-OECD countries improve their scientific and technical capabilities. Recent analysis based on firm-level data indicates that MNEs make sizeable contributions to productivity growth in their home and host countries and are important conduits for technology transfer. Policy should focus on improving the attractiveness of the domestic economy to foreign affiliates and to ensuring spill-overs from their activities, such as by encouraging linkages with local firms and suppliers.

In 2000, the combined expenditure of the top *500 global R&D performers* in the private sector amounted to € 307.4 billion. This amounts to almost twice the total R&D expenditure in the whole of the EU that year. The European share of R&D investment by the top 500 companies is not very large. It amounts approximately to 29% (compared to 44% for US firms). It is important to note, nevertheless, that since 1996, the European share has been increasing more rapidly than its American counterparts (Table 3.4).

	Top 100 firms					Top 500 firms				
	number of firms		% of total R&D		average annual growth rate of R&D investment %	number of firms		% of total R&D		average annual growth rate of R&D investment %
	1996	2000	1996	2000	1996-2000	1996	2000	1996	2000	1996-2000
US	43	43	43.6	44.0	10.3	208	208	43.7	43.8	11.4
EU-15	30	31	24.0	29.2	15.6	132	132	23.6	28.0	16.3
Japan	22	21	26.2	21.6	4.9	127	127	27.2	23.1	7.0
Other countries	5	5	6.1	5.2	5.3	33	33	5.6	5.1	9.0
Total	100	100	100.0	100.0	10.1	500	500	100.0	100.0	11.4

Table 3.4 - Top 100 and 500 firms by trade zones, 1996 and 2000 [12]

Nevertheless, Europe's largest companies invest relatively less than their American or Japanese counterparts in sectors such as information technologies hardware and software. Instead, they tend to focus their R&D spending on automobile and parts or chemicals and pharmaceuticals, sectors where Europe benefits from a particularly strong international position.

German, French and British firms account for most of the European share of top 500 R&D investments (9.7%, 5.8% and 5.3% respectively). Firms from these countries also account for the majority share of European large firm R&D investment, 34.7% (Germany), 20.9% (France) and 19.1% (UK) (Table 3.5).

Country	Number of firms	R&D expenditure in € million	Share in total (500 firms)	Share in EU-15 total (132 firms)
Belgium	2	542	0.2%	0.6%
Denmark	4	782	0.3%	0.9%
Germany	28	29859	9.7%	34.7%
Greece	0		0.0%	0.0%
Spain	2	202	0.1%	0.2%
France	32	17948	5.8%	20.9%
Ireland	1	325	0.1%	0.4%
Italy	7	4538	1.5%	5.3%
Luxembourg	0		0.0%	0.0%
Netherlands	8	5556	1.8%	6.5%
Austria	0		0.0%	0.0%
Portugal	0		0.0%	0.0%
Finland	5	3343	1.1%	3.9%
Sweden	11	6495	2.1%	7.6%
UK	32	16402	5.3%	19.1%
EU-15	132	85992	28.0%	100.0%
US	208	134515	43.8%	
Japan	127	71135	23.1%	
Other countries	33	15787	5.1%	
Total	500	307429	100.0%	

Table 3.5 – Top international companies by number and by R & D investment, 2000 [12]

China is also strengthening its industrial capabilities, raising educational enrolments and worker training, increasing R&D and improving physical infrastructure and (with WTO accession) the investment climate[2]. Chinese R&D reached 1.1 % of GDP in 2002, up from 0.6 % in 1996 – and as much as 60 % of the R&D expenditure came from companies, rather than the government.

3.2 EU's RTD&I spending policy [1, 2]

As the recent economic slowdown gives way to prospects of stronger economic growth across the EU region, renewed attention is being directed to ways of tapping into science, technology and innovation to achieve economic and societal objectives. The continued transition to more knowledge-based economies, coupled with growing competition from non-EU countries, has increased the reliance of EU countries on the creation, diffusion and exploitation of scientific and technological knowledge, as well as other intellectual assets, as a means of enhancing growth and productivity. High-technology industries account for a growing share of EU value added and international trade and can be expected to play a significant role in the economic recovery.

Today the EU devotes only 1.96 % of its GDP to research and development, compared to 2.59% for United States, 3.12 % for Japan and 2.9% for Korea. The gap between US and EU is currently about € 130 billion a year, 80 % of which can be attributed to the difference in private sector spending in research and development.

The production sector is and will remain essential and of strategic importance for Europe. Facing the challenge of a competitive and sustainable European production system, in the coming years, EC recognized the need of a more integrated and encompassing vision of RTD&I policies that takes account of economic, environmental and social dimensions.

The March 2000 Lisbon European Council set the objective of making the EU 'the most competitive and dynamic knowledge-based economy in the world by 2010, capable of sustainable economic growth with more and better jobs and greater social cohesion'. This ambitious target cannot be met without the continuing presence of a strong and competitive manufacturing sector.

Recently, on the occasion of the relaunch of the Lisbon Strategy, the European Council reaffirms that the Lisbon Strategy itself is to be seen in the wider context of the sustainable development requirement that present needs be met without compromising the ability of future generations to meet their own needs. That declaration will serve as a basis for renewing the sustainable development strategy adopted at the European Council meeting in Göteborg in 2001. The new, more comprehensive and more ambitious strategy, comprising targets, indicators and an effective monitoring procedure, will be based on a positive long-term vision and will fully integrate the internal and the external dimensions.

3.3 EU and Member States R&D support in Manufacturing

Research is one of the basic driving forces behind economic and social progress and a key factor in business competitiveness, employment and the quality of life. Recently, EC recognized Europe is still suffering from structural weaknesses where research is concerned.

To face the various challenges, public support for research and innovation in manufacturing technology has steadily increased in Europe since the late 80s. This effort has tended to be more focused during the latter years, directed towards emerging new technologies such as 'nanotechnology' and 'new multifunctional materials'. Table 3.6 indicates the amount of EU public support given to research on manufacturing technologies during the various EC Framework Programmes.

	FP1 (84-87)	FP2 (88-91)	FP3 (91-94)	FP4 (95-98)	FP5 (99-02)	FP6 (03-06)
Programme acronym	Brite	Brite-Euram I	Brite-Euram II	Brite-Euram III	Growth	NMP
EU funds	185 MECU	620 MECU	748 MECU	1617 MECU	2700 M €	1300 M €

Table 3.6 - EU public support to research on manufacturing technologies

To promote a new push in R&D and its effectiveness in Europe in the Sixth Framework Programme (FP6) EC gave the first steps towards a true European Research and Innovation Area. In the FP6 the following objectives are pursued:

Research activities : Improving the performance of European research, in particular through the networking and coordinated implementation of national programmes; networking centres and areas of excellence in the public (in particular university) and private sectors in the Member States; carrying out large-scale targeted research projects, particularly in the field of industrial research.

- *Research and innovation, "start-ups" and SMEs:* Strengthening technological innovation capacities in the EU, in particular by supporting research for and in SMEs, dissemination, transfer and take-up of knowledge and technologies, exploitation of research results and setting-up of technology businesses;

- *Research infrastructure:* Strengthening the European research infrastructure by implementing a European policy in this area, taking into account questions concerning access, operation and construction, and also covering the question of large-capacity electronic networks for research.

- *Human resources:* In support of the development of a knowledge-based economy, strengthening Europe's human resources in science, technology and innovation, in particular by increasing trans-frontier mobility, developing European careers, increasing the participation of women in research and making the scientific professions more attractive to young people and Europe more attractive to researchers from third countries.

- *Science, society and citizens:* Establishing, on a European scale, a new contract between science and society by strengthening the link between research activities and policies and the needs of society, taking greater account of the needs relating to the application of the precautionary principle and the sustainable development principle, as well as the social and ethical consequences of scientific and technological progress.

Three specific aspects have been taken into account with regard to these measures, namely: Firstly, the overall coherence of *European scientific and technological cooperation*; the *regional dimension*; and, *the international dimension.*

In FP6, specialisation can be illustrated by the NMP priority (Thematic Area 3), devoted to ‘nanotechnology and nanosciences, multifunctional knowledge-based materials, new production processes and devices’. A similar focus has appeared in the priority ‘aeronautics and space’ (Thematic Area 4) – a domain that was previously included in the GROWTH programme, but which is now the subject of a specific priority.

The main objectives of FP6 NMP are:

To help provide Europe with the critical mass of capacities to develop and exploit those high technologies at the basis of the products, services and production processes of the future, which are essentially knowledge based.

To develop intelligent materials for applications in sectors such as transport, energy, electronics and biomedicine representing a potential market of several billion euro.

To develop flexible, integrated and clean systems requiring a substantial research effort in the application of new production and management technologies.

FP6 NMP represents a radical departure from previous Framework Programmes. In FP6 new instruments were used to improved research effectiveness to the new demands in all fields including manufacturing, namely:

Integrated Projects (IP) - designed to create the knowledge required to implement the priority thematic areas of FP6, by integrating a critical mass of activities (research, demonstration, training, innovation, management) and resources (staff, skills, competences, finances, infrastructure, equipment etc.).

Networks of Excellence (NoE) - as an instrument for directly tackling the fragmentation of research activities in Europe in a given thematic area.

Article 169 - to support the opening and joining of national research programmes of Member States.

Also, special instruments were established for:

- *SMEs* (Small and Medium-Sized Enterprises) where two special forms of project are available, in addition to the traditional "collaborative" projects where the partners do the research themselves, namely:

- *Cooperative research projects* (CRAFT) where the SME partners commission external research performers (research institute, university etc.) to do the research work.
- *Collective research projects* where industrial associations/groupings commission external research performers to carry out research on behalf of large communities of SMEs.

- *mobility and training* (Marie Curie actions) at transnational level where a variety of possibilities for individual researchers in different stages of their career as well as for institutions acting as hosts for these researchers.

- *research infrastructures* to promote the development of a fabric of research infrastructures of highest quality and performance in Europe and their optimum use on a European scale, providing transnational access to major research infrastructures, networking, joint research, design studies, communication network development and construction of new infrastructures.

In addition to these new instruments the traditional 'shared-cost research projects' of earlier Framework Programmes have been replaced by '*Specific Targeted Research Projects*' (STREPs), improving existing or developing new products, processes or services or contributing to meet the needs of society or Community policies. Also, are supported the: '*Co-ordination actions*' a continuation of the concerted actions/thematic networks used in FP5, intended to strengthen the links between different research initiatives, such as Eureka, COST, ESF, national and Commission RTD activities; and, '*Specific Support Actions*' aimed at supporting the implementation of NMP priority, they include activities such as studies, benchmarks, foresight, elaboration of technology roadmaps and promotion and dissemination of knowledge and good practices.

Complementing FP6, EUREKA – a European initiative oriented towards applied research – has since the 80's also defined the manufacturing domain as one of its priorities. A EUREKA 'umbrella', entitled Factory, is active in this field with the basic purpose to stimulate R&D projects dealing with the future development of production.

Industrial research needs appropriate critical mass and benefits dramatically from an international dimension. International Cooperation represents an important dimension of FP6. This involves the opening of the seven thematic areas, among which NMP, to participation by researchers, teams and institutions from third countries.

All third countries can participate in RTD actions (in addition to the minimum number of participants from Member States and accession countries) if their participation is well justified and if their participation is well integrated into the work programme activities.

A budget of 285 million Euro is available across all thematic priorities for funding third country participation in RTD actions. The following third countries can therefore be funded: the "INCO" countries - developing countries; Mediterranean partner countries; Western Balkan countries, Russia and other newly independent states.

There are also a series of bi-lateral agreements for scientific and technological cooperation with Argentina, Australia, Canada, Chile, China, India, Russia, South Africa and USA, in which partners from these countries cooperate with EU countries with possible aid of their own national funding.

A specificity of NMP is the Intelligent Manufacturing Systems initiative with Norway, Switzerland, Canada, USA, Japan, Australia and Korea. This is a multi-lateral agreement allowing research collaboration between the EU and these other member regions.

The creation of a European Research Area (ERA) for industrial technologies is seen as the way to involve all Member States in meeting the interlinked challenges of competitiveness, environmental sustainability and employment.

Prospects of stronger economic growth across the EU provide new opportunities to enhance support for science, technology and innovation. Many Member States have introduced new or revised national plans for science, technology and innovation policy, and a growing number of them have established targets for increased R&D spending.

Virtually all EU countries are seeking ways to enhance the quality and efficiency of public research, stimulate business investments in R&D and strengthen linkages between the public and private sectors. Public/private partnerships (P/PPs) have emerged as a key element of innovation policy and are attracting a growing share of financing.

Human resources for science and technology have also re-emerged as a primary concern among policy makers, especially as relates to the availability of sufficient supplies of skilled workers (including scientists and engineers) to sustain innovation-led economic growth and restructuring.

Governments have introduced a range of reforms to strengthen public research systems and to enable them to contribute more effectively and efficiently to innovation. Funding structures have also been changed in many countries to make universities and government laboratories less dependent on institutional (*i.e.* block grant) funding and more reliant on competitively awarded project funds for research. Many countries have stepped up efforts to evaluate public research organisations, with a view toward improving the quality of teaching and research.

Member States are also taking steps to improve technology transfer from public research organisations to industry. Governments continue to reform rules governing the ownership of intellectual property (IP) generated by public research institutions, in most cases granting ownership of IP to the institution in order to encourage commercialisation of research results and provide greater consistency in IP management among research organisations.

These are the challenges addressed by the Lisbon strategy agreed in 2000. However, progress towards its goals has fallen well short so far, calling for a decisive impulse which may put it back on the right track. The objective is to turn the European economy into one of the most attractive to invest, to produce and to work. This requires a new impulse for reforms that lead to a significant improvement in the business environment; boosting research and innovation in key sectors; and modernizing European labour markets and social protection systems.

Recently, the European Commission has unveiled its plans for the Seventh Framework Programme (FP7), which propose a duration of seven years (2007 to 2013), a estimated budget of 73 billion euro and a structure based on four specific programmes: Cooperation, Ideas, People and Capacities.

Within these four programmes, 'Cooperation' refers to collaborative transnational research activities; 'Ideas' covers basic research implemented through a European Research Council (ERC); 'People' includes Marie Curie actions and other initiatives; while 'Capacities' encompasses support to research infrastructures, regions of knowledge and small and medium sized enterprises (SMEs).

The proposals stress that collaborative research, under the Cooperation heading, 'will constitute the bulk and core of EU research funding'. Indeed, nearly 45 billion euro of the total 73 billion euro budget would be channelled towards this priority under the Commission's plans. As well as collaborative research, the Cooperation programme will cover Joint Technology Initiatives (a new way of realising public-private partnerships at European level) [11], coordination of national research programmes and international cooperation.

Nine thematic areas for collaborative research are specified: health; food, agriculture and biotechnology; information and communication technologies (ICT); nanosciences, nanotechnologies, materials and new production technologies (NMP); energy; environment (including climate change); transport (including aeronautics); socio-economic sciences and the humanities; and security and space research.

As with FP6, the largest of these thematic areas in budgetary terms is ICT, with a proposed allocation of 12.7 billion euro over seven years. Next comes health with nearly 8.4 billion euro, followed by nanosciences with just under 5 billion euro. The newly created security and space research priority is set to be the fifth largest, with a budget of 4 billion euro, while the other new thematic area, socio-economic sciences and the humanities, will be the smallest with a budget of 797 million euro.

As expected, under the Ideas programme, the Commission foresees the funding of individual projects suggested by researchers on subjects of their choice. The programme will be implemented by an ERC independently of the rest of the Framework Programme, with a proposed budget over seven years of 12 billion euro.

It is proposed that the People programme will cover the initial training of researchers (through the Marie Curies networks), life-long training and career development, industry-academia pathways and partnerships, and international activities including incoming and outgoing fellowships and the exchange of researchers. The proposed budget allocation is the lowest of the four specific programmes at 7.2 billion euro.

The Capacities programme, meanwhile, will target the optimal use and development of research infrastructures, strengthening the innovative capacities of SMEs, the development of regional research clusters, improving the research potential in EU convergence regions, and improving the integration of science and society. To achieve these aims, the Commission proposes a budget of 7.5 billion euro.

Compared with its predecessor FP6, proposals for the new programme place far less emphasis on the specific funding mechanisms that will be used. For transnational projects launched under the nine thematic areas, three main instruments are identified: collaborative projects, which will range form small-scale, focused research actions to large integrating projects (IP), Networks of Excellence (NoE) bringing together a number of institutions in a given field, and coordination and support actions, such as networking, exchanges and access to research infrastructures.

Concerning the Thematic Area 4 - *Nanosciences, nanotechnologies, materials and new production technologies* aims to improve the competitiveness of European industry by transforming it from a resource-intensive to a knowledge-intensive industry, by generating breakthrough knowledge for new applications at the crossroads between different technologies and disciplines. A total 4865 million euro budget is expected to be channelled towards this Thematic Area.

The main activities in the Thematic Area 4 will be

• *Nanosciences, Nanotechnologies* - Generating new knowledge on interface and size dependent phenomena; nano-scale control of material properties for new applications; integration of technologies at the nano-scale; self-assembling properties; nano-motors; nano-machines and nano-systems; methods and tools for characterisation and manipulation at nano dimensions; nano and high-precision technologies in chemistry; impact on human safety, health and the environment; metrology, nomenclature and standards; exploration of new concepts and approaches for sectoral applications, including the integration and convergence of emerging technologies.

• *Materials* - Generating new knowledge on high-performance materials for new products and processes; knowledge-based materials with tailored properties; more reliable design and simulation; higher complexity; environmental compatibility; integration of nanomolecular-macro levels in the chemical technology and materials processing industries; new nano-materials, bio-materials and hybrid materials, including design and control of their processing.

• *New Production* - Creating conditions and assets for knowledge-intensive production, including construction, development and validation of new paradigms responding to emerging industrial needs; development of generic production assets for adaptive, networked and knowledge-based production; development of new engineering concepts exploiting the convergence of technologies (eg, nano, bio, info, cognitive and their engineering requirements) for the next generation of high value-added products and services, and adaptation to the changing needs.

• *Integration of technologies for industrial applications* - Integrating new knowledge and technologies on nano, materials and production in sectoral and cross sectoral applications such as: health, construction, transport, energy, chemistry, environment, textiles and clothing, pulp and paper, mechanical engineering.

The rationale behind this Thematic Area are:

- The decline in industrial activities appears no longer to be limited to traditional sectors with a high labour intensity, but is beginning to be observed in intermediate sectors – which constitute the established strengths of European industry – and even in some high-technology sectors. This trend can and must be reversed by building, in Europe, a strong knowledge based, knowledge intensive industry. This will include the modernisation of the existing SME base and the creation of new knowledge-driven SMEs, from the dissemination of knowledge and expertise through collaborative programmes.

- The EU has recognised leadership in fields such as in nanotechnologies, materials and production technologies which must be strengthened in order to secure and increase the EU position in a highly competitive global context.

- European Technology Platforms in fields such as nanoelectronics, manufacturing, steel, chemistry, the transport industry, construction, industrial safety, textiles, pulp and paper help establish common research priorities and targets. In addition to industry relevant priorities and their integration for sectoral applications, the relevant policy, regulatory and standardisation, and impact issues will be addressed, including by responding flexibly to new policy needs that arise.

Besides the EC efforts the long term impacts on growth, social cohesion and environmental performance of a further integration of research and innovation systems into a European system are nevertheless difficult to assess: recent scenarios tend to show that a more integrated Europe as well as a globalised Europe score both higher in terms of efficiency/equity trade offs than "Europe of Regions" or a "Transatlantic" Europe; but the first one is more socially cohesive and environmentally sustainable but less economically effective than the second[15].

3.4 Research Challenges to EU manufacturing[2]

For European industries to remain competitive in the increasingly complex global economic environment, it is crucial that they modernise their manufacturing base and strengthen the links between research and innovation.

A more integrated view of the arena for innovation sees production and consumption as key parts of socio-technical systems. Socio-technical systems include technologies, products and materials 'in use' and human systems. Innovations arise through design – purposeful processes of change that engage many actors (producers, consumers and others). An integrated view has other dimensions. It brings together economic, environmental, social and scientific concerns. It requires solutions tailored to specific socio-technical systems and localities under the influence of national, European and global pressures.

A particular issue is the way globalisation is creating new axes for the governance of technological and social innovations. This means future innovation must be governed in ways that are responsive to global competitiveness and innovation, environmental concerns and social needs, while harmonising public policies and business strategies through collaboration and joint action. This runs counter to most existing policies and practices for RTD&I. It has implications for the orientation of environmental and industrial policies as well as industrial practice.

This orientation builds on a number of trends in manufacturing and adopts some known and simple principles. For example, production is becoming progressively more resource efficient, and manufacturers are increasingly addressing consumers' needs for product performance. There is also a strong link between the development of knowledge and innovation, as the foundation for competitiveness, and, the achievement of environmental and social sustainability. This link is provided by ideas about learning organisations and multiactor (social) learning platforms. These emphasise collaborative processes for developing visions, systems thinking, problem finding and problem solving, and resolving barriers to change and joint action.

A diverse combination of factors - from greater productivity arising from technological change in the goods industries, a shift of demand in high income countries from goods to services in spite of declining relative prices for goods, intense global competition, including from newly industrializing economies - is leading to a decline in the share of GDP arising from goods production in all developed countries.

In the emerging knowledge economy, there is a shift from goods industries to knowledge and person-based industries in terms of the composition of GDP and employment. But it is not that one group of industries is replacing another. While there is some increased demand for services as final products, activities related to the creation, production and distribution of goods still lie at the heart of advanced economies. But those activities are becoming increasingly knowledge and service intensive, so that there is growing convergence between what are traditionally regarded as goods industries (such as agriculture, manufacturing and mining) and service industries. For example, enterprises engaged in manufacturing rely heavily on services, both from within the firm and outside it, and sell both goods and services. Many service sector firms are totally focused on providing services to manufacturing firms, or to firms producing other types of goods.

The shift is increasingly towards building a long term, strategic relationship with customers to service their total package of needs based around a manufactured product.

A concerted effort will be needed to transform European manufacturing from a resource-intensive to a knowledge-intensive, innovative sector with all the strengths necessary to achieve and maintain leadership in the global marketplace[2].

The manufacturing industry has faced significant challenges over the past 25 years and rapid changes are certain to continue. The new information and communications technologies, and the processes of globalization which have been associated with them, have already changed the face of manufacturing. Much of manufacturing is now *globalize*, in the sense that a wide range of functions from R&D and marketing to production and distribution are now undertaken on an integrated global basis; *networked*, in that the coordination of these functions makes intensive use of electronic networks and of virtual and geographical clusters of expertise; *customized*, in that methods of production must allow for detailed customization of products to meet the needs of individual markets and individual consumers; and *digitized*, in the sense that many of these processes, and particularly final production, are controlled by advanced computers systems which limit the need for human intervention.

Recently, within the MANU*FUTURE* conference the main topics discussed covered the main aspects of the MANU*FUTURE* High Level Group's recommendation, which address the above mentioned evolution in Manufacturing, namely[17]:

- *Innovating production* – boosting the move from an economy of quantity to one of quality, from an economy of use and waste to a sustainable economy;
- *Adapting the organisation* – replacing linear approaches by a 'manufacturing engineering' strategy that simultaneously addresses all inter-related aspects;
- *Adaptive and digital manufacturing* – using digital methods to integrate new technologies into the design and operation of manufacturing processes;
- *Networked and knowledge-based manufacturing* – using knowledge to optimise resources and processes, as well as transferring it to areas where it can be employed to advantage; and
- *Providing a supportive environment* – in terms of integrating the factory environment with education, and developing better solutions for the financing of innovation.

Inevitably, the range of opinions that emerged in this discussion was wide, but some points of broad cross-group consensus can be summarised as follows:

Research focus

- Establish *a horizontal MANUFUTURE Platform* to provide a holistic view across the whole field of manufacturing. More targeted actions should be the responsibility of sector-specific platforms.

- Pursue *long-term goals*, but do not ignore shorter term needs. SMEs in particular have a short time horizon, and valuable resources could disappear if they are not supported in the period before radical breakthroughs emerge.

- Link research themes more closely to *industrial needs*. Consider market potential at the initial stage, and target an early return on investment. This will increase the likelihood of industrial participation

- Seek more efficient methods for *knowledge capture*, benchmarking, comparison and updating. Recognise SMEs as repositories of traditional knowledge and skills that may be lost with the export of manufacturing jobs. Use them as ‘technology scouts’ in partnerships with larger organisations.

- Investigate *the robot/human interface* in order to permit safe and flexible interaction.

- Consider *environmental issues*, and promote energy-saving solutions

Transforming processes and organisations

- Develop tools to map and simulate *new, flexible business concepts* to cope with rapid technological advance and changing approaches to markets – more than one per organisation may be needed. New business models must be based on an initial evaluation of industry’s day-to-day problems, and the solutions should be designed for wide implementation.

- Focus on *adaptive and digital manufacture* as the main vectors for the transformation of European industry. Engineers will increasingly design products, systems and entire factories in a virtual environment, but it is important not to lose sight of ‘real world’ experience. Aim for detailed simulation of the cost of implementing virtual designs.

- Explore methods for faster, more efficient *factory start-ups and adaptation*. Consider factories as complex products in themselves.

- Think about *nanotechnology* even for large-scale products. Nano-surface technology and functional elements will become increasingly relevant in all kinds of applications.

- To facilitate collaborative working, adopt *Europe-wide standards* for the exchange of systems and tools.

- *Share new technologies* such as mechatronics with embedded electronics, and cognitive ICT. Do not be afraid to copy – no single organisation can innovate in every area.

- Create *network structures* in which the participants are interoperable rather than integrated, enabling each company and institute to retain its autonomy. Formulate standard descriptions of partners and resources, to allow maximum flexibility in adding/exchanging elements according to emerging needs.

- Develop methods for *cost-benefit allocation* in co-operative research. Determine how start-up losses, as well as benefits, should be distributed.

Education and dissemination

- Implement the ‘*teaching factory*’ concept, drawing lessons from the on-the-job training of hospital doctors.

- Promote active exchange, whereby *educators* spend time in industry and industrialists take full- or part-time teaching posts.

- Aim to bridge the gap between the openness of academia and the closed attitude of industry with regard to *knowledge sharing*.

- Make use of local *technology transfer centres*.
- Give industry a greater role in the **specification** of educational systems.
- Use a *case-study* approach to present students with actual industrial scenarios.
- Address *complexity and multidisciplinarity* in curricula.
- Combine *entrepreneurship training* with technical studies.
- Place more emphasis on *ethical issues* in teaching programmes.
- Simplify *Europe-wide accreditation*. Enable students to pursue modular education, recognised by a 'personal passport' of skills rather than a rigid qualification.
- Seek to *inspire innovation* in vocationally trained young people, as well as in the academically-oriented. Also consider how older people can be encouraged to innovate.
- Influence *the very young* to become interested in manufacture.
- *Publicise* industrial successes and create visibility for manufacturing 'world champions'.

Supportive environment

- Improve the *stability of research policy* – avoid major disruptions at three/four-year intervals.
- Reduce the *administrative workload* involved in preparing research project proposals
- Try to equalise *Member State funding*, possibly through the use of structural funds.
- Globalise *patent law* and facilitate IPR protection.
- Make research more accessible to *SMEs* – e.g. through fiscal incentives, knowledge vouchers giving access to academic resources, encouragement of networking and partnership with large enterprises.
- Provide *incentives* for scientists to work in industry
- Make better provision for innovators and company employees to *gain reward* for their contributions.
- Redefine *social standards*, so that factories become more attractive as workplaces.
- Devise mechanisms for the promotion of *public/private partnerships*.
- Simplify access to *venture capital*, and persuade European businesses to become more ready to seek funding.

Some of these issues have been already addressed successfully but future research policy and activity should take in to account these general points for a healthy and competitive European Manufacturing sector.

Besides *MANUFUTURE* analysis other studies have been carried out by other platforms within and outside EU. Based on these studies the following subsections summarize the main challenges manufacturing is facing, including the ones related to manufacturing enterprises and workforce.

3.4.1 - Manufacturing Challenges[2, 3, 4, 16, 18-20]

The socio-economic and technological drivers pose various challenges for European manufacturing in the future. Industry and policy makers need to reconcile policies and approaches with the objectives of sustainable development and to address these challenges proactively and on time.

The rapid advances of science and technology and emergence of new manufacturing technologies, spurred by intense competition, will lead to dramatically new products and processes. New management and labour practices, organizational structures, and decision-making methods will also emerge as complements to new products and processes.

Several studies identified major factors (technical, political, societal and economic) shaping the future and influencing the environment of manufacturing over the next ten to fifteen years that can guide current investments in manufacturing research. Table 3.7 summarises for the five considered studies the main key drivers of this change. The framework and focus of these studies are differentiated but a clear convergence of future challenges and issues emerged. These can be summarized as seven "Challenges" that lie at the heart of the future manufacturing enterprises, which will influence research:

Manufacture Challenges for 2020[3]	**IMTI manufacturing roadmap**[17-19]	**FutMan Future of Manufacturing in Europe 2015-2020**[16]	**Manu*future* 2003**[17]	**IMS Vision 2020** [4]
Achieve concurrency in all operations	Lean, Efficient Enterprises	Globalisation and an increasingly competitive business environment	Increased research and technological development	Concurrency
Integrate human and technical resources to enhance work-force performance and satisfaction	Customer-Responsive Enterprises	Socio-demographic change	International cooperation in manufacturing research	Integration of Human and Technical Resources
“Instantaneously” transform information gathered from a vast array of diverse sources into useful knowledge for making effective decisions	Totally connected Enterprises	Environmental issues and sustainability	The key role of education and training	Conversion of Information to Value Creation
Reduce production waste and product environmental impact to “near zero.”	Environmental Sustainability	Societal values and public acceptance of technology	Need for a stimulating operating environment for industrial innovation	Sustainable Management Systems
Reconfigure manufacturing enterprises rapidly in	Knowledge Management	The regulatory environment and the system of European	An increased competitiveness of European research	Reconfigurable and Flexible Enterprises

response to changing needs and opportunities		governance		
Develop innovative manufacturing processes and products with a focus on decreasing physical dimensions	Technology Exploitation	Advances in science and technology		Innovative Processes

Table 3.7 – Manufacturing challenges for different foresight studies

- *Increasingly competitive global economic climate*[2, 3, 4] - The European manufacturing sector will be confronted with an increasingly competitive economic climate and global competition, will require rapid responses to market forces leading to the need for rapid innovation. The pressure on industry to successfully compete in globalized markets will require rapid responses to continuously changing business environments. Geo-political factors, such as the future balance of economic and political powers between the main economic regions, the emergence of new economic powers (for example China, India, Korea, Malaysia, Indonesia, and Brazil), global priorities in the governance of trade (e.g. WTO), political instability and threats of terrorism and armed conflicts that may limit energy and resource availability are also likely to bear heavily on manufacturing. Furthermore, there will be a continuous increase in foreign direct investment in manufacturing outside Europe;

The context in which manufacturing companies work in the future will depend even more on flexibility and speed, as well as on localised production. Manufacturing is also likely to become increasingly service intensive. This service orientation (servation) of manufacturing and the increased customer demand will have consequences for the organisation of production, supply-chain management and customer relations.

- *Anticipate new market and societal needs*[16] - New customer demands and new societal needs will put pressure on industry to come up with new products and services. Sophisticated customers will demand products that are customized to meet their needs, creating in this way new markets and new societal needs. New market and societal needs refer to areas such as safety and security, health care and health technology, energy supply and transportation.

The recent enlargement to EU-25 represents new market opportunities and locations for production. At the same time Europe is becoming increasingly culturally diverse, a process that can open new business opportunities for the manufacturing sector

Further increases in the life-time expectation of Europeans, the increased cultural diversity as a result of immigration and the enlargement process in the European Union will affect many industries; will lead to rising demand for affordable health services and technology to improve quality of life. Security is another key issue for the future.

At the level of the labour supply, the manufacturing and research sectors will be confronted with the retirement of the current large age groups, while innovation might require completely new sets of skills – the availability of which, in both manufacturing and research, could become a critical factor; The issue of workforce mobility and the availability of skilled personnel might become a critical factor for manufacturing.

Industry and the manufacturing sector will also have to contribute to make Europe more knowledgeable and to prepare its member states to compete in the global digital economy.

- *Rapid advances in science and technology*[2, 16-17] **-** Technological progress specifically in the fields of nanotechnologies, materials science, electronics, mechatronics, ICT and biotechnology will enable manufacturers to innovate and offer better products and services to their customers in the future. The development of new production processes based on research outcomes, and the integration of hitherto separate technologies exploiting the converging nature of scientific and technological developments, may radically change both the scope and scale of manufacturing. New energy technologies and nanotechnology in particular, and the increasing convergence of physics, chemical, and biological sciences provide prospects for a wide range of product and process innovation. Progress in these RTD areas might also require completely new sets of skills and may change our understanding of production and consumption. The intensive uptake of new information and communication technology might alter the role and spatial allocation of the various actors involved in the manufacturing chain (from product design and processes to physical distribution).

- *Increase supply chain efficiency*[3, 4, 16] **-** Global competition will put pressure on European industry to provide new products and services individually tailored and based on cutting-edge technology with higher quality, distinctive features and better prices. Competitive climate will lead to a considerable decrease of time-to-market. This process will require new concepts for the organisation of supply chains and offer new business opportunities for manufacturers. Virtual and flexible production networks are among the concepts to increase the efficiency of the supply chain. Production is likely to become more customer-tailored and increasingly service-intensive, which will also have consequences for supply-chain management. Manufacturers may have to acquire new technological and business competencies (e.g. those required for high-quality service provision; feed back loops between customers and design processes).

The global distribution of highly competitive production resources, including skilled workforces, will be a critical factor in the organization of manufacturing enterprises. New organisational architectures in manufacturing might emerge with a rather small number of large scale component manufacturers that are globally distributed, and a large number of regional and local companies for assembly and product finishing linked to local markets. Virtual and network companies linked through instant data-exchange might become reality in the next ten years. In response to market pressure, manufacturers will be looking for new opportunities to expand beyond already saturated markets – particularly by adding service components to their products. As a consequence, manufacturers might give more attention to the development of integrated product-services. If such a trend gains momentum, manufacturers will have to acquire new technological and business competencies.

- *Environmental challenges and sustainability requirements*[2, 3, 4, 16, 17] **-** Environmental protection will be essential as the global ecosystem is strained by growing populations and the emergence of new high-technology economies. The manufacturing sector will have to comply with stricter environmental regulation in the future to minimise the environmental burden of production and consumption. Markets, too, may demand more environment-friendly materials and products. To realise efficiency gains, manufacturers should adopt energy- and resource-saving technology. Industry needs to give attention to extending the lifecycle of products through recycling and to the substitution of hazardous substances and materials. It should be also noted that 'new technologies' offering remedies to current environmental problems, could also create new ones. Europe could strengthen its competitive advantage in sustainable manufacturing by the adoption of new, alternative materials that allow the conservation of resources. Closely related to resource conservation is recycling of materials. In some cases recycling processes themselves face both environmental and economic challenges. Recyclability might be better incorporated into product design, to make disassembly of products at the end of their lifecycle easier. More easily recyclable and reusable materials could also be used. Improved process design and more efficient process technology may also contribute to improved resource efficiency.

Although radical environmental innovation in manufacturing might be potentially the most sustainable ones (e.g. transition towards renewables, closed production and consumption chains, dematerialisation of production), they represent significant investment and risk for the manufacturing industry in the short run. Unless environmental innovation can demonstrate clear market potential, its uptake may be slow. Consequently, weak market forces remain a challenge, and the role of regulation (including international agreements on trade, the environment and sustainable development) remains an important driver of environmental progress. Consumer associations and the civil society may put increasingly pressure on policy makers if industry fails to act on reducing the health, safety and environmental risks and burdens of production.

A stronger orientation of individual, corporate, and societal attitudes towards sustainability might make change easier. The use of management tools such as life-cycle-analysis and environmental management systems may also contribute to more efficient production processes and products. More attention might be given in the future to implement corporate social responsibility policies in manufacturing companies.

- *Integrate new knowledge and improve workforce skills*[2, 4, 16] - Another upcoming issue for sustainable manufacturing is enhancing knowledge integration and organisational learning. This challenge relates to the better integration of human and technical resources, information and knowledge management, innovation management, training of workforce through new training tools and methods, multidisciplinary approaches and the improvement of ‘soft-skills’ such as communication

A broader notion of manufacturing will require linking material and information flows within networks of suppliers and customers more effectively, posing new challenges for information and knowledge management. Success in manufacturing might depend increasingly on the performance in managing knowledge and complex networks. Data on all aspects of the value chain needs to be integrated and processed in real time in order to be effectively assimilated and to support both day-to-day business processes and long-term decision-making. Within factories, demand will grow for ICT-supported process optimisation, integrating hardware, software, operators’ knowledge and after-sales services. If flexible production partnerships become more important, it can be expected that companies increasingly need to adjust the size and skills of their workforce.

It is likely that innovation processes in the future require intense internal and external collaboration to capture in-house knowledge, feedback from users, information provided by suppliers and a vast array of data from external knowledge sources. If multidisciplinary teams become more common, especially in high-tech production sectors, staff need to broaden and share their knowledge and they need to understand the vocabulary and fundamental concepts of those with whom they collaborate.

The intellectual property rights (IPR) system might have to respond to changes in an innovation process that is increasingly based on knowledge sharing and networking.

The emerging knowledge economy may be producing increasing rather than decreasing inequality, both within and between nations. The issue of how this is to be avoided will be a fundamental in future. In particular, it may require some radical rethinking about how knowledge is controlled and shared.

Socio-demographic change in Europe will probably confront manufacturers in future with a considerably older workforce. The emphasis of labour market policy is likely to shift from managing quantity to building quality. The availability of a skilled workforce is likely to become a critical factor in manufacturing, with companies competing to maintain human resources. The manufacturing sector will seek staffs that are able to work in flexible environments and collaborate in multidisciplinary teams. Increased workforce mobility might offer both an opportunity and a threat to manufacturing companies, since the knowledge of individuals cannot easily be maintained when they leave or change jobs. Industrial training and lifelong learning are likely to become critical for manufacturing companies to remain competitive. The new skills will have to deal both with new technology (such as nanotechnology and ICT) and also with interdisciplinarity and knowledge management

Assuming that industrial training and lifelong learning become critical issues for manufacturing companies, the education system face pressure to adapt and introduce training on new skills starting from the school system up to the university level and postgraduate courses. This raises the question how labour market policies and publicly funded training programmes, can be better targeted to transfer competencies more effectively. Companies might be urged to create more links with the education system. This also implies the foundation of new courses at schools, universities, and industrial training organisation to meet the needs of industry.

If industrial success is to lead to increased employment, a key requirement will be for effective communications highlighting the achievements of European manufacturers and underlining the attractions of careers in the emerging knowledge-based sector.

- *Societal values and public acceptance of technology*[2, 16] **-** Recent debates on ethical implications of science and technology (e.g. stem cell research) or the reluctance of citizen in many European countries to accept nuclear power as a means to cut CO2 emissions have highlighted the need to take public concerns seriously when science and new technology is being adopted and exploited. Nanotechnology and new ICT clearly have the potential to spark future debates on the risks of new technology. Security issues might also become increasingly important and may conflict with privacy concerns (e.g. through ubiquitous computing).

These issues may affect EU manufacturing industry in that the successful marketing of new products and their acceptance by consumers and citizens will depend on their values, attitudes, needs, skills and experience with the features of new technological products and services. At the same time, it should be noted that this could lead to Europe falling behind in some areas of technology.

3.4.2 - Manufacturing Enterprises[3, 18-20]

To attain the future challenges manufacturing enterprises have to progress towards:

Customer-Responsive Enterprises - Future manufacturing enterprises will leverage a robust global communications infrastructure and customer-centric design, manufacturing, and life-cycle management systems to conceive, build, deliver, and support innovative products and services that directly satisfy diverse customers' needs and wants.

Customers will require that suppliers of goods and services maximize the value relationships among quality, service, and price. The goal of successful enterprises will be to find the optimum position in this "better-faster-cheaper" competitive triangle. A "we *can* have it all" attitude among consumers will force corporations to become extremely flexible and adaptable. As large numbers of consumers in newly developed countries gain economic power, this attitude will be prevalent worldwide.

Totally Connected Enterprises - Future manufacturing enterprises will be seamlessly interconnected among all their internal functions and external partners and stakeholders. This will enable operation of complex distributed supply webs and extended enterprises that interoperate as an integrated entity irrespective of geographic separation.

The structure and identity of companies will radically change to encompass virtual structures that will coalesce and vanish in response to a dynamic marketplace. All activities that are not essential to implementing new ideas in marketable products will be eliminated. A readily available generic transaction and alliance infrastructure (e.g., equitable profit sharing and business processes for protecting intellectual property) will enable individuals and entrepreneurial teams to compete solely on the basis of skills and knowledge.

Although production resources will be distributed globally, fewer materials enterprises and more regional or community-based product enterprises will be linked to local markets. Product enterprises may be part of larger corporations, but they will be located in and serve local markets and will operate autonomously.

Reconfigurable Enterprises - New systems technology will enable innovative processes to focus not only on developing new products, but also on creating optimal enterprise configurations. Enterprises will be aggregations of people connected to each other by mutual trust and supported by an alliance and transaction infrastructure. The integrated enterprise system will be dynamic, continuously changing in response to new opportunities. Team-like organizations will form around new product ideas and quickly assemble the necessary resources from a highly distributed manufacturing capability. All aspects of developing a manufacturing enterprise, including developing business and marketing strategies, research, and product innovation, will be concurrent.

Lean, Efficient Enterprises - Future manufacturing enterprises will use technology as a key parameter in the lean equation to achieve new levels of efficiency. Intelligent controls, expert systems, improved supply chain management, and exploitation of emerging technologies will radically reduce the cost and time of designing, manufacturing, delivering, and supporting products.

Knowledge-based Enterprises - Future manufacturing enterprises will be able to capture individual expertise and experience for efficient reuse and draw on a rich, openly accessible shared base of scientific, business, and process knowledge to make informed, accurate decisions and to ensure the right people get the right information at the right time to do their jobs. Improved understanding and shared knowledge of the scientific foundations for material and process properties and interactions will support optimized process design and total understanding of complex transformations and interactions at the micro and macro levels.

Technologic Innovative Enterprises - Future manufacturing enterprises will leverage revolutionary technologies that radically change the way they design, build, and support products.

Environmental Sustainability - Future manufacturing enterprises will draw on a rich base of scientific knowledge, innovative materials and unit processes, and total integration of product life cycles and facilities to cost-effectively design, manufacture, support, and recycle products with no adverse impacts to the environment.

3.4.3 - Workforce[3, 21]

Rapid technical change is shifting the structure of manufacturing towards more complex technology- and skill-intensive activities. It is also increasing technological and skill requirements *within* activities.

The manufacturing workforce will be as diverse as the global economy. Interpersonal skills will be highly developed, cross-cultural barriers will be greatly reduced, and remaining differences will be valued for their contributions to innovative manufacturing.

A diverse workforce, operating on a more level playing field, will have a greater potential for creating new products synergistically.

Individual workers will learn not only through access to information, but also by being important elements of a highly integrated manufacturing system.

As automation advances toward more "human-like" capabilities, workers will be freed to do what is uniquely human—create valuable new products and make bold and visionary business decisions.

3.5 - R&D Challenges based on recent studies[3, 4, 17-20]

Manufacturing will remain one of the principal means by which wealth is created. It is essential that European Union be prepared to implement advanced manufacturing methods in a timely way. A critical step in preparing for the future will be the development of an underlying technical foundation through research by industry, academia, and government institutions, which must be guided by a clear vision of manufacturing in the next decades and an understanding of the fundamental challenges that must be met to realize this vision.

The basis of competition will be creativity and innovation in all aspects of the manufacturing enterprise. Fundamental advances in materials science, processing technology and equipment, and information and controls systems will radically change the manufacturing environment. New net-shape technologies will replace downstream processes and drive the creation of final product toward earlier stages in the manufacturing cycle. Processing steps that cannot be replaced will be improved for efficiency and control in producing products to satisfy the ever increasing demands of customers and other stakeholders.

There is a need for the development and implementation of a European manufacturing strategy based on research and innovation which would promote industrial transformation, secure and create high added value employment and ensure the maximum possible share of world manufacturing output.

Many industries have developed technology roadmaps for their specific business sectors; however, has been a small concerted effort to address technology requirements and associated barriers that cut across multiple sectors. Many of the industry-specific plans mention cross cutting infrastructure needs, but the challenges they present are beyond the ability of any one group of companies to solve.

In this context, as mentioned before, the European Commission promoted a number of sector-specific ‘vertical’ action plans and Technology Platforms for specific sectors such as chemicals, construction, paper, steel, textiles and transport and others like *FuTMaN*[16]**,** MANU*FUTURE*[2,] and IMS Vision 2020[4] go one step further to address issues that can be applied across the whole sphere of manufacturing in a synergistic manner.

The FuTMaN project sought to assist the European Commission for FP6 in examining what technological, knowledge and organisational capabilities might be required by European manufacturing, if it was to remain both competitive and sustainable by the year 2020. Particular attention was paid both to technological priority areas and to any policy changes required. Three cross-cutting approaches to exploring the problem were adopted. *Scenarios* were developed to provide imaginative, coherent views of the threats and opportunities which manufacturing might face in the years to 2020. Three broad strands of manufacturing were studied – *Materials, Transformation Processes* and the *Structure of Industry*. Four sectoral case-studies were undertaken in the *Automobile Industry – Personal Cars, Measuring, Precision and Process Control Instruments (MPPCI), the Semiconductor Industry and Basic Industrial Chemicals.* In addition, a separate integrating study examined the implications which *Governance, social attitudes and politics* might have on the transformation of industry.

MANU*FUTURE*[2] establish a powerful vision encompassing the complex network linking human and societal needs to both the industrial and education system as a tool to guide the development foresight into the strategic future of manufacturing.

The IMS Vision 2020 Forum[4] comprising International leaders and decision makers from industry, research, education and government and was convened in Irvine, USA during February 2000. The purpose of the Forum was to share views on future directions and underlying issues arising from the globalisation of manufacturing in the first part of this century. The Forum was convened and supported by IMS (Intelligent Manufacturing Systems), a multinational program for cooperation in the development of manufacturing technologies and systems.

Other international studies were produced like Visionary Manufacturing Challenges for 2020[3] and the Integrated Manufacturing Technology Roadmapping (IMTR)[18-20].

The Committee on Visionary Manufacturing Challenges was established by the National Research Council's Board on Manufacturing and Engineering Design (1) to create a vision of the competitive environment for manufacturing and the nature of the manufacturing enterprise in 2020, (2) to determine the major challenges for manufacturing to achieve the vision, (3) to identify the key technologies for meeting these challenges, and (4) to recommend strategies for measuring progress. The year 2020 was chosen to encourage thinking about revolutionary changes, rather than evolutionary advances based on current capabilities.

The IMTR initiative delivered roadmaps for four core technical areas, namely: Information Systems for Manufacturing; Modelling and Simulation; Manufacturing Processes & Equipment; and, Technologies for Enterprises Integration. IMTR was a focused effort, sponsored by the National Institute of Standards and Technology (NIST), U.S. Department of Energy (DOE), National Science Foundation (NSF), and the Defense Advanced Research Projects Agency (DARPA), to develop a manufacturing R&D agenda that cross-cuts the diverse needs of government and industry across all major manufacturing sectors.

The framework and focus of these studies are differentiated but a clear indication of future research challenges and issues emerged.

All these studies identified major enabling technologies shaping the future and influencing manufacturing up to 2020 that can guide current investments in manufacturing research. Table 3.8 summarises the enabling technologies for the five considered studies.

Manufacture Challenges for 2020[3]	**IMTI manufacturing roadmap**[18-20]	**FutMan**[16] **discrete parts and process manufacturing**	**Manu*future* 2003**[2]	**IMS Vision 2020**[4]
Adaptable, integrated processes & systems readily reconfigurable	Knowledge repositories & validation centres	New processing technologies for new materials	Information and communication technologies	Systems modelling particularly human-machine interfaces and processes and subsystems that enhance human performance and promote intelligent input
Manufacturing processes that minimize waste and energy consumption	Intelligent design & process advisors	Miniaturisation	New materials and new design paradigms	Design methodologies that draw on libraries of reusable design modules
Innovative processes for designing and manufacturing new materials and components	Intelligent control systems	Mechatronic modules	Miniaturisation and precision engineering	Technologies that provide people with models of causes and effects, and ways to experiment in a safe but realistic environment
Biotechnology for manufacturing	Distributed control across extended enterprises	Nanotechnology in manufacturing	Integrative approaches, e.g. mechatronics, process control	Technologies that support participative design and contextual inquiries to accelerate the design process.
System synthesis, modelling, and simulation for all manufacturing operations	Science-based manufacturing	Modelling and simulation	Extended products	artificial intelligence and decision support systems that handle huge image bases in a variety of languages
Technologies to convert information into knowledge for effective decision making	Zero life-cycle waste	Product life cycle planning	New technologies for tomorrow's products	intelligent agents, active knowledge filters tailored to individuals and knowledge structuring tools to prevent "information overload."
Product and process design methods that address a broad range of product requirements	First part correct	Flexible manufacturing systems		Accurate models of the effects of processes and materials on long-term environmental quality, quantification and comparisons of risks

Table 3.8 – Enabling technologies for different foresight studies in manufacturing

Manufacture Challenges for 2020[3]	**IMTI manufacturing roadmap**[18-20]	**FutMan**[16] **discrete parts and process manufacturing**	**Manu*future* 2003**[2]	**IMS Vision 2020**[4]
Enhanced human-machine interfaces	Innovative breakthrough processes	Process integration		Development of new and advanced materials to replace non renewable resource based materials
New educational and training methods that enable the rapid assimilation of knowledge	Engineered materials &surfaces	New concepts for process control and sensor technology		Software technologies, such as language design and compiler optimisation, object-oriented and distributed databases, and virtual reality, focused on the manufacturing context
Software for intelligent collaboration systems	Freeform manufacturing	Intelligent manufacturing/ Near-net shape processes		Uniform standards for exchanging product/manufacturing information along complete value chains and value networks.
		Process improvement and development		Image prototyping as the sole precursor to full scale production
				Interface between the nano-sphere and the micro and macro sphere of manufacturing

Table 3.8 (cont.) – Enabling technologies for different foresight studies in manufacturing

3.6 - Recommendations for medium-term research[3, 4, 16, 18-20]

As mentioned in the previous section advances in science and technology, especially in materials science, microelectronics and information technology, biotechnology and nanotechnology will profoundly affect manufacturing and help manufacturers master the challenges ahead. On the other hand, facing the challenge of a competitive and sustainable European production system, in the period to 2020, will require a more integrated and encompassing vision of RTD&I policies that takes account of economic, environmental and social dimensions. However, given the diversity of needs and the varying levels of economic development currently existing in nations across the enlarged EU, no single solution can meet all cases. Here, the intention is to define broad strategic research concepts leading to ideas that can be applied, shared and adapted across countries, regions and industries.

The establishment of the Strategic Research Agenda (SRA) in Manufacturing for the next decades is currently one of the main tasks of the MANU*FUTURE* platform. Without pretension to dim this outcome, based on previous foresight studies this subsection summarises some medium-term key research topics in manufacturing grouped in five broad cluster: (1) new materials, processes and products in manufacturing, (2) Information technology, (3) modelling and simulation, (4) manufacturing processes and equipment, and (5) enterprise integration.

New materials processes and products in Manufacturing[3] In recent years, advances in materials science have already led to the development of new products and improved services. In the future, knowledge-content materials, providing new functionality and improved performance, raise the prospects for product and process innovation in manufacturing. The availability of advanced materials will enable the production of smaller, smarter, multi-functional, and more easily customisable components and products. New materials may also play an important role for stimulating and enabling technology development in other high-tech industries such as the ICT sector. Finally, they may provide the basis for sustained innovation in more traditional sectors like construction (e.g. lighter and easy to assemble materials).

Innovative processes to design and manufacture new materials and components will enable the manufacture of innovative, customized, waste-free products. The goal will be to develop new classes of materials with extraordinary physical properties (e.g., strength, wear characteristics, and electromagnetic properties). With miniaturization, new classes of "intelligent" products will be produced, but miniaturization at submicron scales will require materials with properties that can be controlled at the molecular scale. The processes for designing new materials and their components, especially submicron-sized components, will require design methodologies based on atomic and molecular physics and chemistry. In many cases, the materials will be organic, and the design methodologies will be biologically based. The processes for manufacturing these materials and components may require manipulation at the atomic level (nanofabrication), processes akin to gene splicing, and perhaps biological processes. Innovative processing methods include nanofabrication and improved net-shape processes, Figure 3.7.

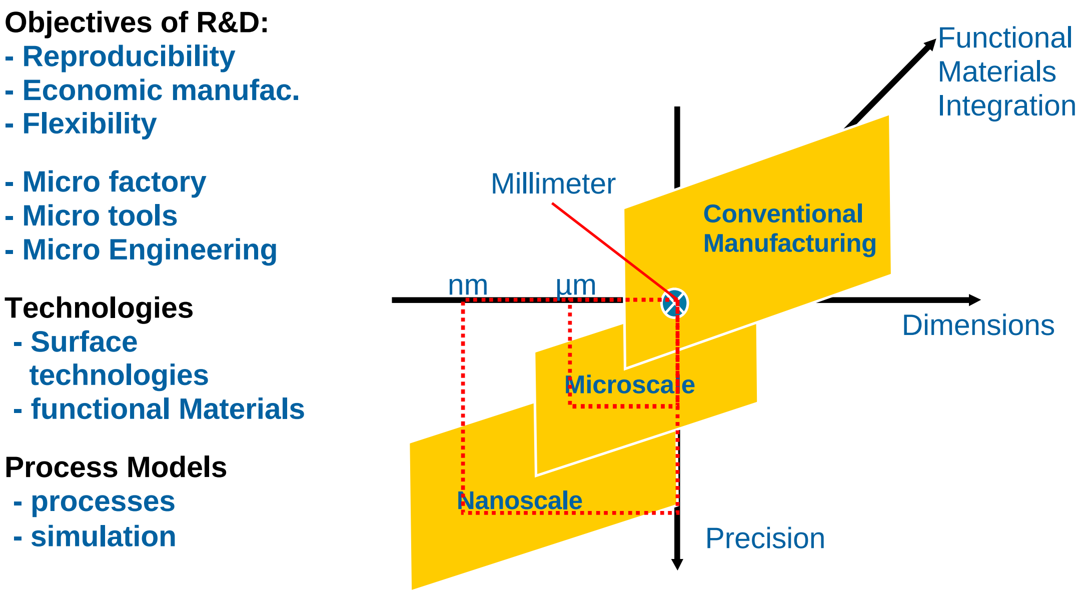


Figure 3.7 – Miniaturisation in Manufacturing [23]

As enabling technologies are developed, the trend toward small-scale production components will continue. Extremely small-scale process building blocks that allow for synthesizing or forming new material forms and products will emerge. Nanofabrication processes will evolve from laboratory curiosities to production processes. Molecular assembly of complex, precise functional structures will lead to the development of micro devices, such as sensors, computational elements, medical robots, and macroscopic devices constructed from fundamental building blocks. Biotechnology, combining biology and chemistry, will lead to the creation of new biosynthetic and bio derived manufacturing processes that will have new and exciting applications on the shop floor of the twenty-first century.

The focus on sustainable, low-waste production processes will intensify as the global ecosystem is strained by growing populations and the development of new high technology economies and as awareness and global economic forces increase the need for responsible environmental stewardship. Improved process controls, the recycling and reuse of process waste streams, and new synthetic pathways will result in near-zero discharge processes. Products will be designed to be recyclable and reusable or to exist benignly in the environment.

Table A2.1 in Appendix 2 summarises some relevant research topics on new materials, processes and products to manufacturing[18-20].

Information technology (IT) is a vital part of today manufacturing. Information technology is also a double edged sword. It enables manufacturers to enjoy the benefits of advanced tools and techniques, such as simulation, modelling, robotics, and connectivity with customers, partners, and suppliers. Yet it is also driving enterprises to respond ever more quickly to new threats and opportunities. Information technology will continue to change at breakneck speed, doubling in performance while halving in cost as quickly as every 18 months. This will bring dramatic changes in the way products are manufactured. Manufacturing in the future will leverage IT to enable fast and cost-effective transition from concept to product, instantaneous availability of all manufacturing knowledge, and innovative products that are 100% accurate and reliable.

Table A2.2 in Appendix 2 summarises some relevant research topics on information systems for manufacturing[18-20].

Modelling and simulation (M&S) are emerging as key technologies to support manufacturing in the 21st century, and no other technology offers more potential to improve products, perfect processes, reduce time to market, and cut product realization costs. The real value of M&S tools is their ability to represent knowledge to make confident predictions – predictions to drive product design, process design and execution, and management of the enterprise. The development costs can be significantly reduced by investing more in the initial design stage, using M&S tools to optimize products and processes in the virtual realm before committing resources to physical production. Beyond design, simulation tools can greatly help improve the efficiency of manufacturing processes.

Table A2.3 in Appendix 2 summarises some relevant research topics on new materials, products and processes to manufacturing[18-20].

Manufacturing processes and equipment[20] operated and managed by skilled people, will always be the heart of the manufacturing enterprise. The production assets available to the enterprise through its internal resources and those of its partners, vendors, and suppliers largely determine: the range and features of products that can be produced for its customers; product quality and reliability; production costs and rates; the amount of utilities consumed and waste generated during manufacturing; capital investment requirements and, therefore, return on investment; and, how quickly and well the enterprise can respond to changes in market forces and customer needs.

Manufacturing processes and equipment will undergo radical changes in the future in response to the drivers of lower costs, environmental responsibility, and ever-more demanding customers. The change in the way products are translated from concept to delivery will be dramatic, and will be enabled and accelerated by the emerging ability to integrate manufacturing – from requirements, to design, to product. Manufacturing processes will be much more precise, flexible, and adaptable, and process optimization will no longer be a buzzword, but a systematized reality.

There are several major enablers that will make this new manufacturing environment a reality. Advances in the fundamental understanding of interactions between materials and processes will enable creation of comprehensive, science-based process models. Such models will dramatically improve the efficiency, predictability, yield, and control of processes and equipment. Process models and related information will be accessible to all users and developers through a shared global knowledge repository. This will enable all users, particularly smaller firms, to select the best operating parameters for performance, responsiveness, and profitability.

Improved process knowledge based on a solid foundation of math, physics, and chemistry will give rise to the creation of knowledge-based advisory systems that use material and product requirements as inputs and produce the needed manufacturing information, including process parameters, product and tooling designs, and control data for execution. These advisory systems will help product and process designers optimize the total manufacturing design and execution process rather than just a single operation.

The information generated by the product/process design systems and other sources will be directly downloaded to flexible processing equipment that will operate in a closed-loop environment to always deliver correct product. Critical parameters will be automatically measured and processes adjusted on the fly to deliver product that meets all requirements, without inspection or certification. Rework will be eliminated. Feedback of operational performance will assure that the enterprise knowledge base is continuously updated.

In many cases, material preparation operations will deliver finished, net-shape products. In other cases, process steps and transformations will be minimized and optimized to provide the best path to the correct product. New technologies at every step of the manufacturing process will build upon a scientific foundation to enhance the efficiency and performance of every operation and product.

Environmental responsibility will become a driver for excellence instead of an onerous requirement, and energy efficiency will be built into every process step. Longstanding environmental issues will be resolved through replacement or reengineering of environmentally adverse processes with environmentally benign alternatives.

Intelligent controls integrated and interconnected at every level of the production operation – regardless of geographic separation – will integrate information gathering, analysis, and processing functions into self-learning environments that address overall manufacturing performance and enable total process control. Equipment and process controllers will be integrated with higher-level decision support systems to enable greater flexibility, productivity, safety, and surety than ever.

Future controllers will feature advanced functionality, modular designs, open architectures, and will be built on standard computing platforms that enable true plug-and-play integration. Application programming interface (API) specifications will be replaced over time with intelligent-object and agent-based architectures that enable new equipment and process functions to self-integrate into the total manufacturing operation.

Process equipment will reach new levels of efficiency, reliability, and performance. Modular designs will shrink lead times for equipment purchase, reduce acquisition and maintenance costs, and lead to great efficiency in all types of manufacturing. Although large pieces of equipment will continue to exist, small, special-purpose equipment that supports processing in "one-piece flow" fashion will proliferate. Reliable operation at extreme operating conditions, with uptimes of 100%, will be realized through improved machine designs, on-line sensing and diagnosis of all critical components and parameters, and automated corrective actions.

Table A2.4 in Appendix 2 summarises some relevant research topics on manufacturing processes and equipment[18-20].

Enterprise Integration (EI) connects and combines people, processes, systems, and technologies to ensure that the right people and the right processes have the right information and the right resources at the right time. EI enables successful operation, in a world of continuous and largely unpredictable change, of a single manufacturing company or an ever-changing set of widely dispersed extended (or "virtual") enterprises – by enabling quick and accurate decisions and adaptation of operations to respond to emerging problems and opportunities.

Table A2.5 in Appendix 2 summarises some relevant research topics on enterprise integration[18-20].

4. SWOT analysis of EU manufacturing industry

Strength	**Weakness**
- EU seeks scientific excellence and new ways of tapping into science, technology and innovation - EU-15 is now the best performing world region in terms of number of publications - Public support for research and innovation in manufacturing technology has steadily increased in Europe since the late 80s - EC support the strengthening of European research infrastructures - International Cooperation represents an important dimension of Framework Programs - EU countries are seeking ways to enhance the quality and efficiency of public research, and stimulate business investments in R&D - Member States are taking steps to improve technology transfer from public research organisations to industry - European Technology Platforms will help to establish common research priorities and targets - The establishment of a horizontal MANU*FUTURE* platform will improve EU research on manufacturing in the coming years - Europe has taken on board the sustainable development dimension.	- The growth in patents is stagnated indicating that EU innovation activity and transfer to industry is too weak - S&T development and innovation in Europe has a positive trend but needs to be improved to outperform the main competitors - Productivity growth in European manufacturing industry as a whole has been below US levels in recent years - World research investment shows EU is clearly behind its main competitor in the worldwide scene - Enterprises in Europe are clearly not investing enough in research - European share of R&D investment by the top 500 companies is not very large (29%) when compared to US (44%) - Europe's largest companies invest relatively less than their American or Japanese counterparts in sectors such as ICT, hardware and software. Instead, they tend to focus their R&D spending on automobile and parts or chemicals and pharmaceuticals, sectors where Europe has strong international position.
Opportunities	**Threats**
- EU seeks new ways of tapping into science, technology and innovation - EU increased the R&D intensity establishing explicit targets to boosting R&D expenditure - EC recognized the need of a more integrated and encompassing vision of RTD&I policies that takes account of economic, environmental and social dimensions - EC supports research for and in SMEs - EC created new instruments to improved research effectiveness to the new demands in manufacturing - Collaborative research, under the Cooperation heading, 'will constitute the bulk and core of EU research funding' in FP7 - , EC funding of individual projects suggested by researchers on subjects of their choice, under the Ideas programme, will lead to innovation - European enterprises is that the majority are SMEs giving flexibility and innovative character - Manufacturing is likely to become increasingly service intensive - The recent enlargement to EU-25 represents new market opportunities and locations for production.	- Weak economic conditions limit investments in science and technology - Eastern European countries decreased R&D intensity - Progress towards Lisbon strategy goals has fallen well short so far - The decline in industrial activities appears no longer to be limited to traditional sectors with a high labour intensity, but is beginning to be observed in intermediate sectors - European manufacturing sector will be confronted with an increasingly competitive economic climate and global competition - Although radical environmental innovation in manufacturing might be potentially the most sustainable ones, they represent significant investment and risk for the manufacturing industry in the short run. - The manufacturing and research sectors will be confronted with the retirement of the current large age groups, while innovation might require completely new sets of skills - Workforce mobility and the availability of skilled personnel might become a critical factor for manufacturing - Ethical and security issues could lead to EU fall behind in some technological areas.

5. Forward look over next 10-15 years

There are countless questions that one can raise about the future, and the methods by which the scientific community, the corporate sector, and society approach the issue of tomorrow's world are correspondingly diverse.

This section is obviously very speculative in the sense that no one can successfully predict the future. Also, it does not intend to be another foresight or visionary study that usually is linked to future scenarios of our economic and social development. Instead, it presents some general long-term research recommendations to meet the challenges forward in sections 2 and 3 of this report that are in line with the changes occurring in our civilization.

5.1 Looking far ahead in science and technology

As mentioned before the general trend of our civilization is shifting from industrial to knowledge-base society. However, as point it out by Albert Einstein "Imagination is more important than knowledge, because knowledge is limited". However, imagination can be even more important when it's combined with a generous dose of unconventional thinking. This can lead to unforeseen trends in our society and to real breakthroughs in science and technology. For example, the most recent advances in measuring important physical quantities with unprecedented precision, particularly those by Physics 1997 Nobel Prize winners Steven Chu, Claude Cohen-Tannoudji and William D. Phillips offer hope that advances on a similar scale will be made in the measurement of many of matter most intimate phenomena. For example, we can conceive of measurements to the nearest femto-second (10-15), which will enable us to film chemical reactions (femto-chemistry), including reactions in living matter. Similarly, arranging molecules to build computers or explore the net fact that entangled quantum systems can represent not only the values 0 and 1 — as used by conventional computers — but also values in between will enable us possible to accelerate the speed of many calculations by a factor of millions[23].

This major science and technology evolution will allow approaching the speed of living organisms to such an extent that we can already foresee the possibility of creating intermediate entities leading to an explosion of synergies in all fields of science and technology. The pair "matter, energy" will be replaced by the pair "time/living organism".

However, this real breakthrough in science and technology will happen at the end of this century beginning of the next one. Meanwhile, we need to learn how to deal with two key scientific topics that will help to cope in future with the pair "time/living organism" – complexity and cognition. These two new emerging fields will help to understand on the one hand the complexity of the processes we want to model and control, and on the other hand the functions and processes of the mind. Both scientific emerging fields will have a tremendous impact in all other fields of science and technology, including Manufacturing, but also can be currently applied to actual products and processes that are becoming increasingly complex and that we want remarkably intelligent.

5.2 General Research Recommendations[3]

The recent pace of technological advances could lead to complacency and the belief that technology will be available "on demand." Today's advances, however, were the result of exploratory enabling research performed years ago. If Manufacturing is to have the technical capabilities it needs in 2020 (see section 3), the research that will provide the scientific basis for these capabilities must be initiated now.

From the previous analysis the general findings regarding research opportunities in Manufacturing can be summarized as listed below:

- The European Union must not be seen as a second or third choice for research investments. To make it more competitive the following steps are relevant: i) to improve attractiveness of investments in research and development towards European Union; ii) to encourage European researchers to stay in Europe and attract back those that have already left to pursue careers elsewhere; iii) to attract first class foreign researchers; and, to set good well-focused research programs.

- Since Manufacturing is inherently multidisciplinary and involves a complicated mix of people, systems, processes, and equipment, the most effective research will also be multidisciplinary and grounded in knowledge of manufacturing strategies, planning, and operations.

- Substantial research is already under way outside of the manufacturing sector that could be focused on manufacturing applications.

- Many of the areas for research are crosscutting areas, that is, they are applicable to several enabling technologies. Adaptable and reconfigurable manufacturing systems, information and communication technologies, and modelling and simulation are especially important because they are keys to manufacturing capabilities in many areas.

- Two important breakthrough technologies—submicron manufacturing and enterprise simulation and modelling—will accelerate progress in addressing the manufacturing challenges.

- The longer-term manufacturing challenges for 2020 will be meet if research is directed towards development of (1) analytical tools for modelling and assessment, (2) processes for capturing and using knowledge for manufacturing, and (3) intelligent processes and flexible manufacturing systems.

Based on these findings and general conclusions, the following recommendations for a research and development program in Manufacturing and enabling technology areas is appropriated:

Recommendation. Establish an interdisciplinary research and development program that emphasizes multi-investigator consortia both within institutions and across institutional boundaries. Establish links between research communities in the important disciplines required to address the manufacturing challenges, including all branches of engineering, mathematics, physics, chemistry, economics, management science, computer science, complexity, philosophy, biology, psychology, cognitive science, and anthropology.

Recommendation. Focus long-term manufacturing research on developing capabilities in the enabling technology areas to meet the challenges of European Manufacturing.

Recommendation. Establish priorities for long-term research with an emphasis on crosscutting technologies, i.e., technologies that address more than one manufacturing challenge. Adaptable and reconfigurable manufacturing systems, information and communication technologies, and modelling and simulation are three research areas that address several manufacturing challenges.

Recommendation. Establish basic research focused on breakthrough technologies, including innovative submicron manufacturing processes and enterprise modelling and simulation. Also, focus basic research on the development of a scientific base for production processes and systems that will support new generations of innovative products.

Recommendation. Monitor the research and development on technologies that will have significant investment from outside the manufacturing sector and undertake research and development, as necessary, to adapt them for manufacturing applications. Some applicable technologies are listed below:

- information technology that can be adapted and incorporated into collaboration systems and models through manufacturing-specific research and development focused on improving methods for people to make decisions, individually and as part of a group
- core technologies, including materials science, nano- and bio-, energy conservation, and environmental protection technologies.

Recommendation. Industry and government should focus interdisciplinary research and development on the priority technology areas. Some key considerations for the long-term research are:

- understanding the effect of human psychology and social sciences on decision-making processes in the design, planning, and operation of manufacturing processes
- managing and using information to make intelligent decisions among a vast array of alternatives
- adapting and reconfiguring manufacturing processes rapidly for the production of diverse, customized products
- adapting and reconfiguring manufacturing enterprises to enable the formation of complex alliances with other organizations
- developing concurrent engineering tools that facilitate cross-disciplinary and enterprise-wide involvement in the conceptualization, design, and production of products and services to reduce time-to-market and improve quality
- developing educational and training technologies based on learning theory and the cognitive and linguistic sciences to enhance interactive distance learning
- optimizing the use of human intelligence to complement the application and implementation of new technology
- understanding the effects of new technologies on the manufacturing workforce, work environment, and the surrounding community
- developing business and engineering tools that are transparent to differences in skills, education, status, language, and culture to bridge international and organizational boundaries.

5.3 - Summary and Conclusion

Europe has a fairly high research score in manufacturing but it needs to achieve even greater scientific excellence by increasing the attractiveness of manufacturing industry and ensure the competitiveness of its research, otherwise such R&D will be done elsewhere. The next generation of advanced manufacturing and processing technologies will be expensive to produce, and no one entity has all the resources and expertise needed. Cooperative R&D share costs, risks, and expertise is necessary. EU must avoid fragmentation and duplication of its research efforts. Properly managed international cooperation in advanced manufacturing R&D, through EU, can help improve manufacturing operations, enhance international competitiveness, and lead to technology breakthroughs via market-driven R&D. EU should provide a support structure for conducting R&D projects within specific arrangements for the protection of intellectual property rights. Results of R&D projects should be shared through a process of controlled information diffusion that protects and equitably allocates any intellectual property, both background and foreground.

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Appendix 1: Detailed socio-economic SWOT analysis in Manufacturing

Despite our lagging behind the US in R&D investments and overall performance (in terms of patents and high tech trade) Europe is persistently a world leader in terms of quality of life and social cohesion. In addition a number of European countries are ranked above the US in terms of knowledge society composite performance indicators. These European countries have a well known focus on sustainability and social cohesion.

In most sectors, global comparisons show that European manufacturing industry has been, and continues to be, successful in maintaining its leadership. However, this position is menaced on two fronts. On the one hand, EU industry faces continuing competition from the other developed economies, particularly in the high-technology sector. On the other, low-wage economies are increasingly threatening the more traditional manufacturing sectors.

While the pursuit of new production paradigms might involve significant disruption, failure to break the current pattern gives rise to equally serious threats for European industry:

- Competition with low-wage countries in labour-intensive, mass-consumption products will be more and more difficult for EU manufacturers;

- European companies could increasingly resort to delocalisation if the region's environment for business and innovation is not sufficiently favourable[21].

It should be noted that, in EU-15 there were marked differences between the individual Member States as previously mentioned. After the enlargement the industrial landscape of the EU changed considerably since the community embraced a group of countries with relatively low-wage economies, yet considerable technological experience.

The implications for industrial policy have been discussed in an EC Communication 'Industrial Policy in Enlarged Europe'[22] and in the MANU*FUTURE* group[17] which identified further strengths and weaknesses of European industry, namely:

Strengths:

- European industry is modern and competitive in many respects. Most sectors have made significant efforts to upgrade their production infrastructures and integrate new forms of organisation;
- A long lasting industrial culture exists, with large European networks, linking suppliers, manufacturers, services and user companies;
- Europe has taken on board the sustainable development dimension. Significant investment in environmental protection, clean technologies and environment friendly production processes have led to new manufacturing and consumption paradigms; This could give a strong impetus to EU industry, offering the potential to expand and/or create new markets;
- Leading-edge research capabilities are available across Member States, leading to high levels of knowledge generation and a reputation for scientific excellence;
- Some 99% of European businesses are SMEs, which typically exhibit greater flexibility, agility, innovative spirit and entrepreneurship than more monolithic organisations. In addition, SMEs tend to interact in a manner that lies between strong competition and fruitful co-operation, which helps to foster the process of what has been called 'co-opetition';
- Historic and cultural differences between individual Member States and regions bring a diversity of viewpoints and skills that can be coordinated to produce novel solutions.

Weaknesses:

- Productivity growth in European manufacturing industry as a whole has been below US levels in recent years; Increases in ICT and new technology spending over years seems not yet to be translated into productivity gains;
- EU Innovation activity is too weak. The Commission's competitiveness reports of 2001 and 2002 have identified insufficient innovative activity and weak diffusion of new technologies as key determinants for low productivity growth. The EU does not suffer from a lack of new ideas, but is not so good at transforming these into new products and processes. Industry's analysis is that this is due to the framework conditions for manufacturers operating in Europe;
- EU tends to specialise in medium- to high technology and mature capital-intensive industries, while competitiveness in some of the highest value-added segments of the economy is less encouraging;
- Structural problems in the European economy remain, e.g. fragmentation of research activities, obstacles to geographical mobility and pervasive skill gaps for many categories of worker.
- Although a traditional characteristic of Europe has been a good high-level education system, and the average time spent under education by the working population has increased steadily, the EU is currently under-performing the US and Japan. Spending on education as a percentage of GDP has been in steady decline, potentially leading to a weakness in the long term. Threats also exist with countries such as India.
- Another characteristic of European enterprises is that the majority are SMEs (93% micro-enterprises, 6% small, less than 1% medium and only 0.2% large). On average, a manufacturing enterprise provides employment to 16 persons. This characteristic can be related to opportunities (flexibility, innovative character) but also to weaknesses (e.g. smaller export impacts: SMEs export only 13% of turnover, whereas large enterprises gain 21% of their total turnover from abroad). Furthermore, as far as research is concerned, SMEs are more interested to short-term activities, rather than longer-term commitments.

A economic analysis of the manufacturing performance based on OECD studies[14] allows to conclude that during the past twenty years (1980–2000) the world growth rate of manufacturing was slightly lower than that of Gross Domestic Product (GDP) (2.6% yearly for MVA and 2.8% yearly for GDP), due to the growing weight of services in the mature industrial economies that still dominate industry worldwide.

Box A1.1. Definition and classification of transition economies[8]

Definition: economy evolving from centrally planned economy into market economy		
Transition economies in Europe and the former Soviet Union		
	CEE	Albania, Bulgaria, Croatia, Czech Republic, FYR Macedonia, Hungary, Poland, Romania, Slovak Republic, Slovenia
	Baltics	Estonia, Latvia, Lithuania
	CIS	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyz Republic, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
Transition economies in Asia		
	Cambodia, China, Laos, Vietnam	

In the developing world, manufacturing continued to increase its share of GDP. Manufacturing value added (MVA) in developing countries outperformed that of industrialized and transition economies. The developing world's share of global MVA rose from 14 % in 1980 to 24 % in 2000. Transition economies (see Box A1.1, for more details reference [8] suffered a large decline in industrial activity in the early 1990s, a result of the shock of rapid liberalization.

Industrialized countries continue to dominate global manufacturing but are losing ground steadily (Figure A1.1). By 2000 they accounted for 72 % of world MVA; 5 percentage points less than in 1980. This erosion is likely to continue – what is surprising perhaps is how slowly it has been occurring. The gainers are the developing countries, with their share growing by 10 points (from 14 to 24 %). The transition economies lost 5 percentage points of global MVA share.

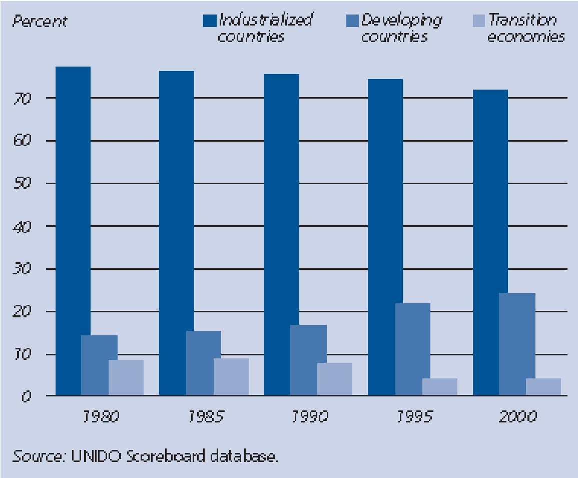

Figure A1.1 - Shares of global MVA[21]

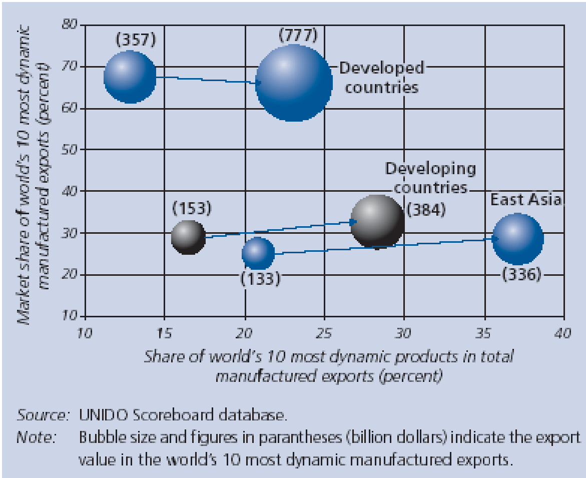

Figure A1.2 - Developed countries keep an edge over developing countries in the world's 10 most dynamic manufactured exports, 1995 and 2000[21]

Similar trends appear in the data on employment where share of industry fell from 33% in 1990 to 32% in 2001[17].

Manufacturing everywhere is becoming more internationalized. Exports have grown consistently faster than MVA, save in the early 1980s when both slowed down. The developing world market share doubled (from 13 to 27 %) in 1980–2000. The industrialized world still accounts for over two-thirds of world manufactured exports, but if current growth rates are sustained the developing world should equal it in less than two decades (Figure A1.3).

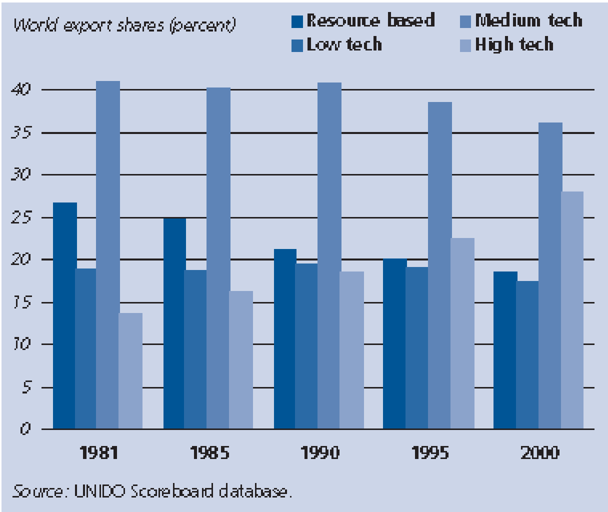

Figure A1.3 - Technology structure of global manufactured exports 1981–2000[21]

The analysis of the structure of manufacturing based on technological content clearly shows that in the industrialised economies, the share of medium- and high-tech production in manufacturing added value rose from 59% in 1985 to 61% in 1998. The corresponding figures were 42.5% and 49% in developing economies – showing clearly that the North-South technological gap, although still high, has partially been eroded.

Medium-technology (MT) products, the 'heavy-industry' products that are the bulk of industrial activity in mature economies, dominate world exports of manufactures (Figure A1.3). Their share is, however, shrinking steadily, as is that of resource-based (RB) products. Low-technology (LT) products expanded their share slightly between 1981 and 1990, but then saw it diminish. The only consistent 'winners' were high-technology (HT) products, which started in 1980 as the smallest category and ended it in 2000 as the second-largest (with a 28 % share). HT products are the fastest-growing category for both industrialized and developing countries in all sub-periods. RB and LT product exports have slowed down significantly over time for the rich countries.

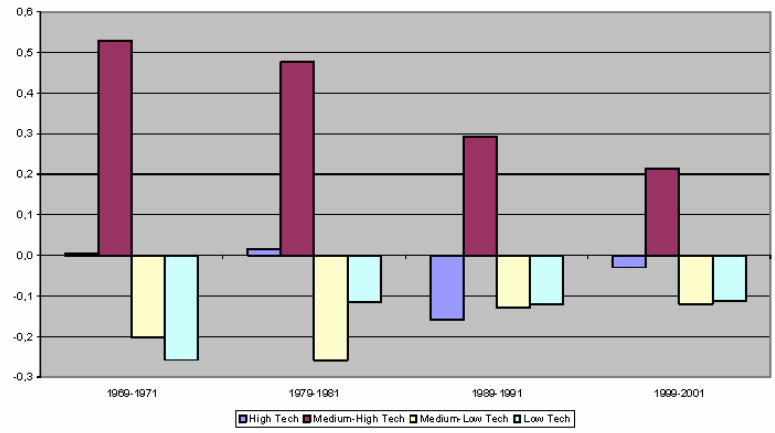

Figure A1.4 – EU-15 trade specialization by technological intensity[21]

Manufacturing as a whole had become more export-oriented since 1980, but the export/production share rose by only 7 percentage points for total manufacturing as compared to 17 points for HT manufacturing.

Concerning trade specialisation, the EU's strengths are concentrated in the medium- and high-tech. sectors (Figure A1.4), and are offset by weaknesses at all the other technology levels. Although the broad features of the EU trade pattern have remained stable over the past thirty years, it is interesting to see that the comparative disadvantage in high-tech products emerged only in the '80s, and was almost completely eliminated during the '90s.

It is worthwhile to point out that during this period some developing countries have built considerable domestic capabilities in high-technology (Figure A1.5), led by the mature Tiger economies of East Asia, the Republic of Korea and Taiwan.

The fifty most dynamic products in world merchandise exports in the 1990s accounted for 38 % of total merchandise exports in 1990 and 50 % in 2000 (Figure A1.6). They grew at 9.4 % per annum over the decade as compared to 6.4 % for total exports and 6.6 % for manufactured exports.

The list has products from all technology categories, including primary products, but, as the Figure A1.6 shows, technology-intensive products predominate. Primary products only accounted for 14 % of total value in 2000, and of this oil & gas accounted for 97 %. Within manufactures, mineral-based RB products accounted for 13 % of the value of the fifty products in 2000, down from 16 % in 1990. The 'fashion cluster' (textiles, clothing and footwear), the group of main interest to many developing countries, only accounted for 4 % of the value in 2000, down slightly from 5 % in 1990. In the MT group, the engineering sub-group has the most dynamic products, with 13 % of the total value in 2000.

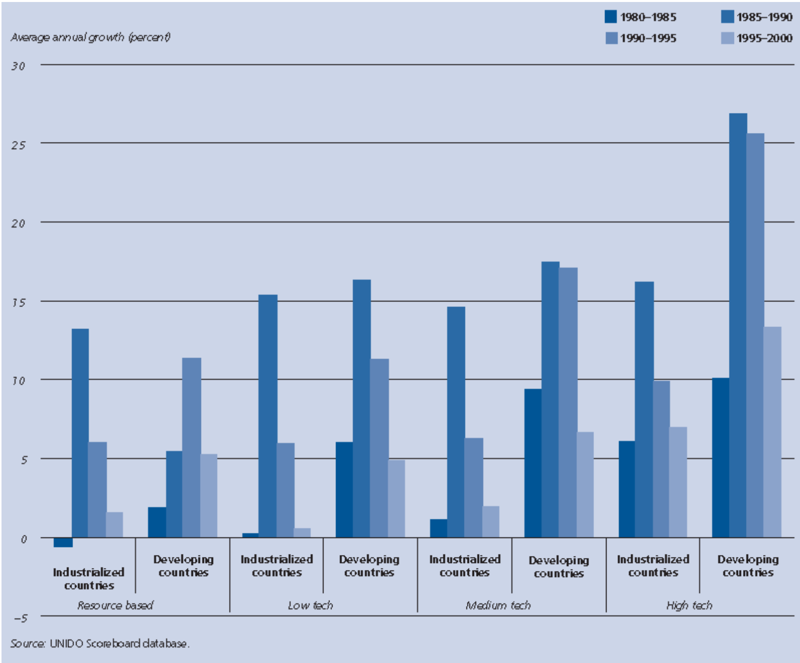

Figure A1.5 - Annual growth of manufactured exports by technology category and economic grouping, 1980–2000[21]

Each technological group within manufacturing has lost shares to the HT category, mirroring trends in aggregate exports, as HT products grew significantly faster than other dynamic products. As a result, they have increased their share of the top-fifty total from 39 to 50 % over 1990–2000. They accounted for 25 % of total manufactured exports by 2000, up from 15 % ten years earlier.

Commodity groups	1990 Export value (million dollars)	1990 Shares (percent)	2000 Export value (million dollars)	2000 Shares (percent)	Growth rate 1990–2000 (percent)
Total 50 products	1 167 240.1	100.0	2 874 428.8	100.0	9.4
Primary	190 188.8	16.3	411 104.1	14.3	8.0
o/w oil & gas	185 138.0	15.9	399 587.0	13.9	8.0
Manufactured	977 051.3	100.0	2 463 324.7	100.0	9.7
Resource based	173 225.1	17.7	358 571.7	14.6	7.5
Agro based	20 192.9	2.1	42 528.6	1.7	7.7
Mineral based	153 032.2	15.7	316 043.1	12.8	7.5
Low technology	160 219.5	16.4	332 585.2	13.5	7.6
Fashion	49 318.3	5.0	104 430.0	4.2	7.8
Other low tech exports	110 901.1	11.4	228 155.1	9.3	7.5
Medium technology	258 538.6	26.5	551 247.6	22.4	7.9
Automotive	52 506.1	5.4	104 354.2	4.2	7.1
Process	59 140.4	6.1	118 991.3	4.8	7.2
Engineering	146 892.0	15.0	327 902.1	13.3	8.4
High technology	383 078.2	39.2	1 218 920.2	49.5	12.3
Electronics	299 366.6	30.6	1 001 742.0	40.7	12.8
Other high-tech exports	83 711.6	8.6	217 178.2	8.8	10.0
All exports	3 072 385.3		5 692 357.2		6.4
All manufactured exports	2 576 443.5		4 883 038.7		6.6

Source: UNIDO Scoreboard database.

Figure A1.6 - The fifty fastest growing world exports, 1990–2000[21]

This trend has implications for developing countries, since more than 80 % of the value of the dynamic HT products comes from electronics, and nearly 40 % of electronics exports now come from the developing world. This is a product that seems ideally suited to drive exports from poor countries: it is growing rapidly in world trade, it is highly income-elastic, it can provide enormous technological and spill over benefits and its processes can be segmented easily. However, the segmentation process has so far advanced in only a handful of countries: the East Asian Tigers (increasingly including China), Mexico and Costa Rica. It is spreading to some East European countries and to North Africa, but the main production system seems to be in place in East Asia. The prospects for its spread to other regions are unclear.

Since MT activities are a major part of manufacturing in most countries with mature industrial sectors, this suggests that the main driver of the growth of medium- high-technology (MHT) is high rather than medium-technology.

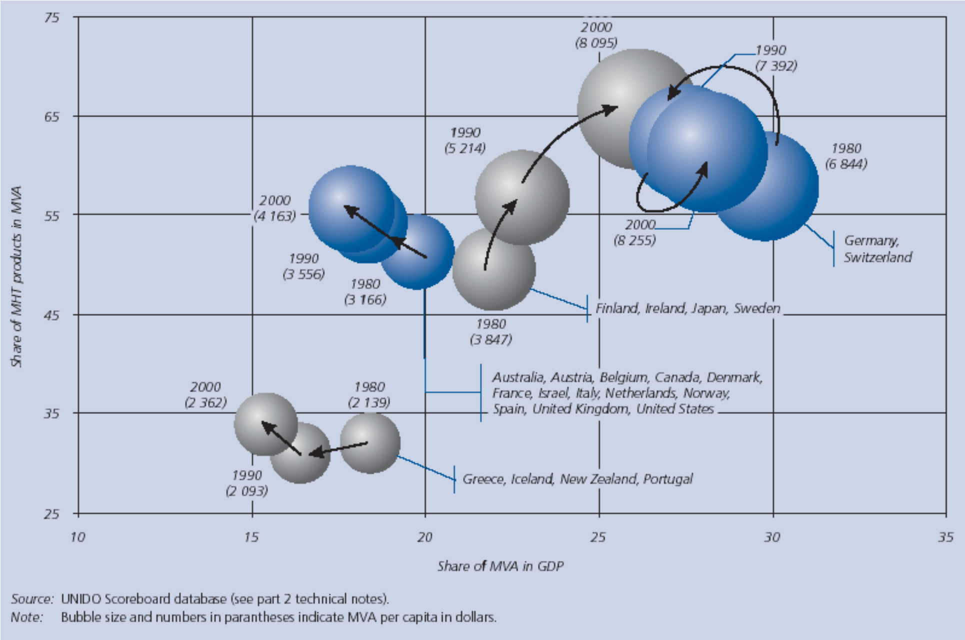

Figure A1.7 - Cluster analysis of manufacturing production in industrialized countries, 1980, 1990 and 2000[21]

Manufacturing industry is becoming less unequal in the world as a whole and in the developing world – in the latter at a considerably faster pace than in the former. Figures A1.7 and A1.8 shows, respectively, for industrialized and developed countries, the evolution of national patterns of industrial and export performance by development levels taking two characteristics of MVA performance: the share of MHT in MVA and the contribution of MVA to GDP. The clusters show countries grouped by the similarity of the two variables while the size of the bubble shows the average value of per capita MVA for each group.

From Figure A1.7 it is clear that within the industrialized world there is a large spread, with the weaker economies well behind the leaders. In the industrialized world, Switzerland and Germany form a cluster with the highest average MVA per capita in all three years; the share of MVA in GDP in this cluster falls over 1980–1990 but rises over 1990–2000 while the share of MHT in MVA rises in the first and declines slightly in the second. The second cluster groups four rather diverse economies: two relative newcomers that have shot up the CIP ranks – Ireland and Finland – and two mature industrial economies with stable ranks: Japan and Sweden. This cluster has most upgraded its MVA structure along both axes. The third cluster has mature economies like UK, US, France and Netherlands along with newcomers like Israel and Spain; in it, the share of MVA in income falls steadily while the complexity of MVA rises. Finally, there is a group of less industrialized rich countries with low average values for both parameters.

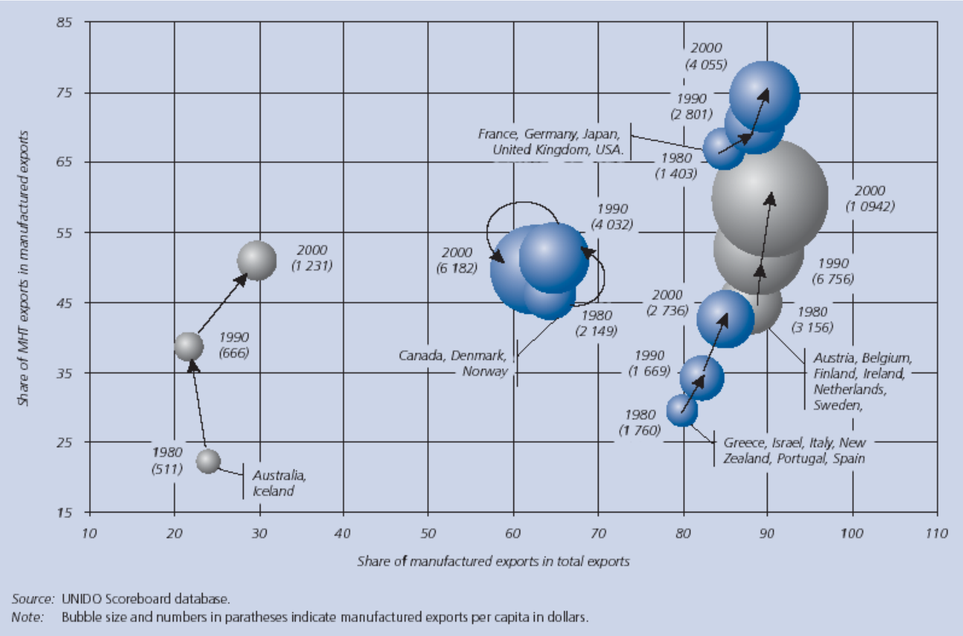

Figure A1.8 - Cluster analysis of manufactured exports in developed countries, 1980, 1990 and 2000[21]

Figure A1.8 shows the export performance, which looks at the share of manufactures in total exports and the share of MHT in manufactured exports. The bubble size reflects the value of per capita manufactured exports.

In the industrialized world, the lead cluster by value of per capita manufactured exports comprises seven small European countries, including Ireland and Finland, along with long established exporters like Switzerland, the Netherlands and Sweden. The group has very high shares of manufactures in exports and has moved steadily up the complexity ladder. The second cluster, with Norway, Canada and Denmark, has high values of per capita exports but has stagnated in terms of upgrading. The third cluster comprises the leading mature industrial powers (France, Germany, Japan, UK and US). It has the most complex export structure and very high shares of manufactures in exports; however, given the size of many of these economies, per capita export values are relatively low. The fourth group – Italy, Israel and Spain – specialises in manufactured exports and has had rapid technological upgrading (if from low levels) along with low per capita export values. The fifth cluster – Australia and Iceland – shows rapid upgrading of the technology structure but low shares of manufactures in total exports and low per capita export values.

The EU and US are still the largest exporters, but their share have gradually been decreasing in the past decades (Figure A1.9).

Asia, and China in particular, is becoming an increasingly potent force in the global marketplace. China's industrial sector has been the largest in the developing world for some time, and its dominance has increased over time. And it was not only concentrated in simple, low-technology activities; its highest share was in MHT products, and this is where its exports were growing most rapidly. Its share of developing-world MVA grew from 10 % to 19 % in RB products, 14 % to 18 % in LT products and 15 % to 21 % in MHT products. Its annual MVA growth rate over 1980–2000 (11.1 %) was more than double that of the developing world (5.4 %) and nearly five times that of the industrialized world (2.3 %).

But, although the exodus of less-skilled production jobs to lower-wage countries is inevitable, many experts foresee positive benefits for the world economy as a whole since machinery imports are particularly important to produce the goods exported. For example, in China its manufactured imports are almost as big as its exports.

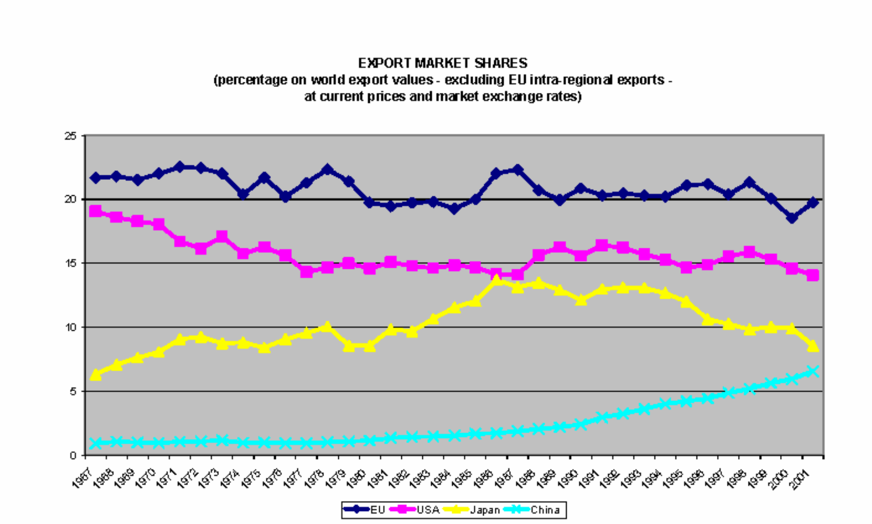

Figure A1.9 – Export market shares[21]

Factors that will keep China from sustaining a large manufacturing trade surplus include a growing domestic market, which will continue to generate demand for imports, and lagging technical competence that will take some time to redress. Trade liberalization will accelerate the upgrading of enterprises and induce greater specialization. While growing Chinese exports pose a significant competitive threat to many countries, this does not mean that China's economic growth will necessarily damage competing economies. Its imports of raw materials, intermediates, components and finished products are rising as rapidly as its exports. The only technological category where it ran a surplus was low technology; in all the others it acted as a catalyst of exports by other countries. Moreover, by serving as an assembly base for exports to other regions, mainly the US and Europe, it strengthened the competitiveness of higher-wage neighbours. The outcome will depend on how well and rapidly competing economies restructure their industrial sectors with respect to China.

The most direct competitive threat from China arises in labour-intensive products, particularly textiles, clothing and footwear, and here it affects economies with similar wage levels. For these economies, the outcome depends on whether they can specialize in niche products, develop other areas of competitiveness or collaborate with China by attracting its enterprises to take advantage of their labour as wages rise in China.

Production and exports within multinational corporations (MNCs), as in electronics, are more cushioned from China's competitive threat as the lead firms organise the system in a way that different segments are located in different countries.

What is not in doubt is that China will prompt a significant restructuring of developing-world manufacturing, and that it will also affect mature industrial countries.

India also envisages the prospect of seizing a substantial share of global contract manufacturing business, which is expected to treble by the end of the decade. With the natural resources and low R&D costs, India has the advantage of generating integrated concepts as well as realising them within its environment[10].

An undoubted threat is the possible joint efforts of China and India towards the formation of a common market.

The socio-economic SWOT analysis in manufacturing is summarized in Section 2.2 of this report.

Appendix 2: Table with relevant medium-term research areas on Manufacturing

New Materials & Processes to Manufacturing[18-20]

Table A2.1 – Relevant research topics on new materials, processes and products to manufacturing

	New Materials Processes and Products in Manufacturing
Nanostructured and hybrid materials	- Nanomaterials with new characteristics, e.g. scratch resistant, self repairing materials, substitutes for additives, low weight – high strength, etc. - Nanosensors and nanodevices - Nanomanipulators and interfaces - Biosensors for control devices; DNA-sensors - Intelligent multifunctional materials for improved performance of instruments - Hybrid materials and components (integrating biotechnological devices)
New polymers	- Bio-polymers (e.g. for polyethylene-substitution, poly lactic acid) - Bio-degradable polymers - Polymers to replace silicon in electronic components - Polymers for light-emitting diodes and displays
New catalysts	- Nanostructured catalysts - Enzymatic and bio-catalysts - Catalytic distillation
Other materials	- Materials for all product lifecycle: disassembly, recycling, waste management - Smart / intelligent materials which could act as sensors by design - New materials for joining technologies - Lightweight materials (metals, polymers, carbon-glass fibres and composites) in design, handling in production, recyclability and dismantling - Aluminium and magnesium materials for manufacturing
New process technology	- Flexible manufacturing and control systems; decision support systems - Human / technology interfaces (e.g. common platforms for data management, for stimulation, storage of data) - New generation of instrumentation for analysis, control, manipulation and manufacture at nanoscale (e.g. nanometrology) - Engineering support for characterisation, testing, up-scaling and eco-design - Interactive decision-support expert systems - Reconfigurable design (in order to make the agents compatible with the new reconfigurable machines) - Monitoring technology and distributed computing - Sensor technology - Net shape processes like hydro forming - Plant and process intensification
New chemical processes	- New membrane technology - Micro-reaction technology - High throughput technology - Reduce production steps in chemical processes - New bio-processes: use plants as chemical reactors (genetic engineering) - Stereo-selective (chiral) chemistry - Proteomics and genomics for pharmaceuticals and health care applications
Processes for improved recycling and resource use	- Processing technologies for all product lifecycle including disassembly, recycling, waste management - Design for closed-loop supply chain - Eco-design of product-service systems with embedded sensors - Optimisation of disassembly processes / smart disassembly / recycling
New product and process design technology	- Design for low capital cost production processes - Virtual reality labs - New product architecture (platforms, modules, services) - Distributed production; smaller & local final assembly sites - New processes for visualisation – visualisation within distributed networks - Modular design for products and production - Financial engineering for plants: build & operate-models

Information Systems for Manufacturing[18-20]

Table A2.2 - Relevant research topics on information systems for manufacturing

	Design, Definition, & Data Interchange
Product Design	- Product design and analytical simulation totally automated and >10X faster - Model-driven virtual prototyping to optimize designs for performance, producibility, and function - Designs and design processes documented and validated using enterprise-wide and shared industry-wide knowledge bases - All appropriate enterprise elements participate in design process
Product Definition & Configuration Management	- Product knowledge bases linked to serve all enterprise elements - Functional and performance models integrated and controlled for each stage of product's life cycle - Knowledge bases contain geometric and non-geometric data in forms (models) that can be easily visualized, shared, and interconnected
Product Information Bridging	- Product data seamlessly exchanged and shared on global basis during all lifecycle stages - Product libraries enable collaboration between individuals, enterprise elements, and extended enterprise partners - Data transferable through real-time exchange of minimally redundant info
	Manufacturing Planning & Execution
Process Design & Definition	- IPPD matured to Integrated Product Realization and process planning for total life cycle, including end-of-life disposition (e.g., recycle) - Common process languages and knowledge indexing schemes - Virtual prototyping and validation of processes and equipment - "Best Practice" design advisors to optimize process designs
Process Planning & Scheduling	- Integrated Enterprise Resource Management (ERM) using generative, controller level process planning coupled to product models - Simulation models used to optimize process plans and resource requirements - Adaptive "on the fly" modification of process plans based on workload, equipment availability, staffing, other factors
Process Monitoring & Control	- Real-time monitoring, control, and optimization of processes and equipment as both individual elements and integrated systems, both factory-wide and enterprise-wide - Operational performance data automatically linked to enterprise information system for continuous visibility of performance and capture of lessons learned
Shop Floor Management & Control	- Autonomous agent-based shop floor scheduling and control - Situational awareness systems that advise managers of factory status and provide alerts of trends and issues - Reactive schedulers that provide new plans to optimize use of resources when conditions or requirements change
	Enterprise Resource Management
Customer Responsiveness	- Direct customer-to-manufacturer ordering systems for custom items - Direct customer participation in design as member of IPPD teams - Comprehensive post-production support (e.g., usage, maintenance/repair, reengineering, reuse, recycling)
Human Resource Management	- Very fast matching of right people and skills to enterprise needs - Clear visibility of current and future skills and knowledge requirements - Knowledge supply chain management will be a core competency - Integrated tools to support creation and operation of collaborative teams
Financial Management & Control	- Continuous real-time visibility of financial performance at all levels (product, unit operation, department, etc.) - Financial knowledge a standard parameter of product design
Asset & Materials Management	- Dynamic asset management that can rapidly match assets to requirements across the extended enterprise - Valuation techniques for intangible assets
Supply Chain Management	- Enterprise participation seen as a seamless part of multiple supply chains - Extended enterprise interoperability - National repository to identify enterprise core competencies

Table A2.2 - Relevant research topics on information systems for manufacturing (cont.)

	Enterprise Resource Management (cont.)
Stakeholder Responsiveness	- Enterprise information systems linked to stakeholder data and requirements - Inverse manufacturing for disassembly, refurbishment, recycle, etc. is standard practice
	Enabling Information Infrastructure
Products and processes	- Ambient intelligence/ embedded systems - Ubiquitous and pervasive systems - Update software/ function with wireless communication system - Device and product assistant system - Information management and communication systems - Expert systems, Fuzzy Systems and Neural Networks (in order to exploit tacit knowledge and to integrate different types of knowledge effectively) - Hidden software solutions - Advanced software techniques (e.g. in order to increase the capability of information processing and to reduce the number of agents)
Networking & Computer Systems	- Real-time access to needed information and knowledge - Zero data loss during transactions; only "net change" data transferred - Secure data communications - Pervasive computing appliances
Common Information Services	- Modular, reconfigurable, self-organizing information systems - Interoperability of user systems and supplier tools
Manufacturing Knowledge Repositories	- Enterprise-specific information on demand - Cross-domain information readily accessible - Use of common data structures and data repositories on national level - Globally standardized methods for multi-domain/enterprise repositories
Shared Tools & Enablers	- Decision support as an integral part of all information systems - Intelligent decision aids that communicate in plain language and access needed internal and external data - Self-learning and self-healing capabilities keep decision support tools current

Modelling & Simulation[18-20]

Table A2.3 - Relevant research topics on modelling and simulation

	Product Modelling & Simulation Functions
Physical Representation	- Object-oriented and feature-based models scaleable from micro to macro levels and containing all product info - Complete interoperability between physical models - Direct linkage to prototyping systems - Collaborative modelling & simulation using integrated environments
Performance	- Performance design advisors and fast automatic performance optimization - Performance modelling & assessment tools plug-compatible with design systems - Multivariate performance analysis
Cost/Affordability	- Cost data available on commodities & downstream life-cycle costs - Performance-based cost modelling - Enterprise-wide cost models
Producibility	- Producibility alternatives automatically modelled during all development phases; autonomous agents to track producibility-related changes for products - Producibility models interoperate with other technical & business models
Life Cycle Considerations	- Environmental & support analytical modules included in or interfaced to product - M&S applications - All life-cycle considerations included in product models, such as recycling, disassembly & disposal
	Process Modelling & Simulation Functions
Technologies for monitoring and security	- Tele-prevention and tele-maintenance/ remote maintenance - Tagging, tracing and monitoring of products and materials - Information security/ encryption technology - Information systems - Smart cards for identification, payment and access. - Solutions which allow interoperability of security systems - Solutions for personal data protection / access / monitoring
Material Processing	- Automated process model creation from design models & enterprise data - Validated, science-based models for all materials - Model repository for reuse - Open, universal framework for M&S standards & model interoperability - Collaborative distributed analysis & simulation systems supporting global distributed manufacturing enterprises
Assembly /Disassembly/ Reassembly	- Immersive VR system for assembly modelling & simulation, with automated optimization - Integrated links to production systems for real-time troubleshooting, change response, & optimization across enterprise & supply chain
Quality, Test & Evaluation	- Virtual system for test & evaluation modelling coupled to test & evaluation knowledge bases - Automated model generation from specifications
Packaging	- On-line virtual system for modelling packaging, including environmental impacts
Remanufacture	- "Reverse engineering" modules to optimize life-cycle performance and re-use - Robust applications integrating all aspects of remanufacturing in initial product and process design stages
	Enterprise Modelling & Simulation Functions
Strategic Positioning	- Strategic decision models with real-time data links - Easy, transparent modelling & simulation
Market Assessment & Positioning	- Domain specific models with links to external & internal information sources - Extensive market assessment models & tools
Risk Management	- Domain & function specific risk models - Risk assessment & avoidance models
Financial/Cost Management	- Predictive cost modelling - Integrated cost & profitability models

Table A2.3 - Relevant research topics on modelling and simulation (cont.)

	Enterprise Modeling & Simulation Functions (cont.)
Resource Management	- Enterprise-wide resource models - Extended enterprise resource models
Quality Management	- Quality impact assessment & trade off tools - Quality no longer a discriminator – all excellent
Enterprise Architecture Management	- Generic enterprise architectures, metrics & modelling tools - Full enterprise architecture models
Extended Enterprise Management	- Techniques for modelling functions across the supply chain - Automated knowledge management across extended enterprise
Operations Resource Management	- Tools & standards for model building & integration - In-depth resource management models
Performance Management	- Accurate data collection techniques for model building - Self-optimizing simulation models
Factory Operations	- Data collection techniques, standards & frameworks - Virtual factory models using real-time data - Modelling and tools to support the design, installation operation and maintenance of novel infrastructures and systems - Simulation of vertical factory integrated systems - Modelling and simulation, based on advanced complex system theories - Replacement of sensors by simulation tools - Molecular design techniques; combinatory chemistry - Modelling and simulation of advanced plant-wide control
Facility Infrastructure Management	- Standard taxonomies & generic infrastructure models - Integrated physical control & performance models

Manufacturing Processes & Equipment[18-20]

Table A2.4 - Relevant research topics on manufacturing processes and equipment

	Supporting Infrastructure
Life-Cycle Product Support	- Products designed for life-cycle support - Tools for disassembly & sorting - Producer responsible cradle-to-grave for product
Waste Management	- Product designs minimize environmental impact - Producer responsible for all waste streams - Zero-residuals production processes; zero-emission facilities and closed-loop recycle industrial parks
New energy sources and raw materials fuel cell technology	- On-board hydrogen storage system for safety and functionality - Fuel cell/ hydrogen - Fuel cell technology large scale production - Clean fuel systems and supply infrastructure (clean energy supply) - Chemical industry: methane, methanol, and carbon-dioxide feedstock - Bio-feedstock (e.g. corn for polymer production – polylactic acid) - Renewable energy resources (i.e. windmills, solar cells) - Batteries technology, Photovoltaic cell technology
Material Handling & Management	- Self-diagnostic systems - Flexible, reconfigurable, autonomous material handling systems
Process Equipment & Facilities Operations & Maintenance	- Smart equipment & facilities - Self-diagnostic, self-healing maintenance - Fault-tolerant system - Rapidly reconfigurable & self-configuring facilities
Equipment & Control Components	- Modular manufacturing equipment with intelligent, model-based, fault-tolerant, open architecture controls - Improved drives
	Material Preparation
Overall	- Shared materials properties databases - Significantly reduced variability between & within production lots - New materials based on molecular engineering - Science-based material models for design and process control - Waste-free processing - Ability to monitor processing in 3-D space - Self-assembling materials - "Broadband" materials insensitive to physical & environmental changes
	Material/Product Processing
Overall	- Knowledge-based advisory systems for processes & tools - Energy-efficient & environmentally friendly processes - National repositories of science-based process models - Net shape products from engineering specifications - Elimination of rework - Optimized life-cycle performance
Material Transformation	- Precise 3-D transformation processes based on direct measurement & control - Miniaturized transformation processes
Material Shaping	- Elimination of hard tooling - Precise 3-D, tool-free shaping processes - Multi-material shaping systems
Material Removal	- Order-of-magnitude improvement in machine tool accuracy & repeatability - High-speed material removal; molecular removal processes - Self-diagnosis/self-healing machine tools - Lubricant- & coolant-free processes
Material Addition & Deposition	- Solid freeform parts fabrication - Hybrid & gradient materials parts fabrication

Table A2.4 - Relevant research topics on manufacturing processes and equipment (cont.)

Material Finishing & Treatment	- Elimination of finishing processes for corrective purposes - Environmentally benign finishing processes
	Assembly
Configuration, Alignment & Orientation	- Flexible, reconfigurable assembly equipment & systems - Automated DFA techniques - Optimized fastenerless assembly processes with cognitive assembly aids - Intelligent, self-configuring assembly systems
Physical Attachment	- Real-time monitoring & control of attachment processes - Defect-free physical attachment processes
	Testing, Inspection, & Validation
Pre-Process	- High-speed characterization of incoming materials & components - Materials & components with self-contained test & inspection data
In-Process	- Integrated error compensation in machine controls - All manufacturing operations contain in-process monitoring & inspection processes
Post-Process	- Many post-process inspection operations eliminated - Products will have self-contained test, inspection, & monitoring data
All Phases	- Self-testing products and processes with embedded metrology - Order-of-magnitude improvement in test & inspection accuracy & cost - Atomic-level test & inspection Advanced sensor, sensor fusion, & signal processing technologies
	Packaging
Shipping Preparation	- Packaging & shipping considerations an integral part of design process - "Green" packaging & total recycling of packaging materials - Packaging with integral product condition monitoring
Marking & Labeling	- Traceable marking & labelling for micro-manufactured parts - Intelligent labels with embedded product information for use, condition, & manufacturing history

Enterprise Integration[18-20]

Table A2.5 - Relevant research topics on enterprise integration

	Integrated Product Realization & Life Cycle Management
Product Realization Management	- Enterprise applications for optimization, dependency tracking, & uncertainty management - Artificial intelligence rebounds
Concept Definition & Optimization	- Real-time virtual prototypes, evaluated & optimized - Customer voice integrated with conceptual evaluation process - Connectivity & interoperability of product requirements & capabilities automated design from requirements - On-line updating & optimizing of conceptual design
Detailed Design & Optimization	- Institutionalized IPPD with automated "cockpits" & mature toolset for optimizing product & process design across extended enterprise - Product/process design based on excellent captured knowledge & real-time &forecasted data - Product represented as single object, including all design, process, & related business/resource data
Manufacturing Execution	- Continuously optimized, real-time enterprise execution & operation using enterprise model as adaptive mfg controller - Manufacturing execution cockpits provide continuous visibility & assist in making best decisions based on enterprise situational awareness - Adaptive, self-integrating equipment & facilities
Product Distribution & Support	- Manufacture/assembly at point of use; real-time routing of orders for distributed fulfilment from mfg “nodes” v"Smart products" support life-cycle reliability (instructions for use, automatic diagnostics, automatic repair)
Product Recovery, Dismantlement & Reuse	- Life-cycle actions pre-programmed into product - Widespread traceability & accountability of manufacturers for products - Clearinghouses provide open access to info about reuse & recycle - Inverse manufacturing/reverse logistics
	Business Operations
Enterprise Management	- Integrated business frameworks & ERM systems facilitate interoperable product realization & business operations - Planning & decision-making based on integration & analysis of accurate, realtime data
Customer & Stakeholder Interaction	- Customer needs immediately satisfied in cost-effective & profitable manner, using full capabilities of extended enterprise - Creation of market based on integrated process capability, enterprise model, & understanding of coming technologies & market conditions
Administrative Management	- Asset modelling tools enable dynamic resource distribution across extended enterprise - Mature Electronic Commerce: complete & automatic electronic sharing of business & technical information between enterprise partners
Supply Chain & Material Management	- Multi-enterprise ERM systems operate seamlessly across extended virtual enterprise - Data protection technologies permit ERM agents to “prowl” networks across extended enterprise - Mechanism for real-time flexible, electronic teaming for dynamic market opportunity response - Ready & fluid access to needed capabilities - Logistic optimisation systems - Logistics for fleet management and product maintenance - Logistics management systems integrated with manufacturing needs across the extended enterprise - Design methods for service sale-of-use

Table A2.5 - Relevant research topics on enterprise integration (cont.)

	Infrastructure Enablers
Integration Planning & Analysis	- Commonly accepted, enterprise-wide reference architectures - Optimal selection of architectures (technical, business, etc.) appropriate for virtual enterprise business strategy - Operating enterprises configured based on definition of current & projected product requirements & resources
Computing/ Communications Infrastructure	- Ubiquitous global networks with virtually infinite capacity & speed - Transparent connectivity & interoperability of all information throughout the extended enterprise - Virtual enterprise relationships enabled in real time, with certified & documented evaluation of trustworthiness, financial status, & risk
Interoperable Systems	- Self-defining emergent systems provide interoperability through understanding of knowledge structures - Integration of “islands of integration” - Open repositories of all information needed by downstream applications, regardless of proprietary sources - Automatic assembly of functional systems from plug-and play hardware & software modules
Knowledge Management	- Global access to global data, information, knowledge, and wisdom across industry sectors - Knowledge capture routinely available & successfully implemented - Corporate knowledge captured from enterprise processes, experience, & insights - Extraction of benchmark processes from global knowledge repositories for specific functions
Energized & Augmented Workforce	- "Best-match" mix of employee skills augmented & tuned to new opportunities by focused training & knowledge support - Just-in-time training via intelligent tutoring & advisory systems - Knowledge systems aid workers to achieve their maximum potential & meet change successfully - Workers incentivized to contribute successfully & stay with enterprises that value & reward their contributions.