



European
Commission



FACTORIES OF THE FUTURE

*Multi-annual roadmap
for the contractual PPP
under Horizon 2020*

Prepared by



EFFRA

EUROPEAN FACTORIES OF THE FUTURE
RESEARCH ASSOCIATION
a MANUFUTURE initiative

Policy
Research

EUROPEAN COMMISSION

Directorate-General for Research and Innovation
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Contact: José Lorenzo Vallés

European Commission
Office COV2 04/055
B-1049 Brussels
Tel. (32-2)29-91757
Fax (32-2)29-58046
E-mail: Jose-Lorenzo.Valles@ec.europa.eu
http://ec.europa.eu/research/industrial_technologies

EUROPEAN COMMISSION

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**MULTI-ANNUAL ROADMAP
FOR THE CONTRACTUAL PPP UNDER HORIZON 2020**

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Executive summary

The importance of manufacturing

Around one in ten (9.8 %) of all enterprises in the EU-27's non-financial business economy were classified as manufacturing in 2009, a total of 2 million enterprises. The manufacturing sector employed 31 million persons in 2009, generated EUR 5 812 billion of turnover and EUR 1 400 billion of value added. The sectors' turnover grew from 2009 to 2010 by EUR 600 billion, up to EUR 6 400 billion. By these measures, manufacturing was the second largest of the NACE sections within the EU-27's non-financial business economy in terms of its contribution to employment (22.8 %) and the largest contributor to non-financial business economy value added, accounting for one quarter (25.0 %) of the total¹. EU exports consist mainly of manufactured products: their share has annually been more than 80 % of total EU exports. In 2011, exports of 'machinery and vehicles' and 'other manufactured goods' together reached EUR 1 000 billion, with an increase of about 40 % in comparison with the lower level of 2009.

Furthermore, SMEs are the backbone of manufacturing industry in Europe. Micro, small and medium enterprises provide around 45 % of the value added by manufacturing while they provide around 59 % of manufacturing employment². Manufacturing is critical for emerging markets: new markets driven by advances in science and innovation will revolutionise Europe's capability to expand manufacturing across traditional and new industries. Manufacturing is an indispensable element of the innovation chain: manufacturing enables technological innovations to be applied in goods and services, which are marketable in the marketplace and is key to making new products affordable and accessible so as to multiply their societal and economic benefits and achieve the desired impacts. Manufacturing is an RD & I-intensive activity. Before

¹ Eurostat.

² Eurostat.

the financial economic crisis in 2008, the R & D expenditure in the mechanical engineering sector in the EU-10 was \$ 8 323 million³. In 2007, the 'manufacturing' sector received the greatest share of business enterprise R & D expenditure in most of the EU-27 countries. The R & D costs and risks involved to keep EU industry competitive and sustainable are too high and feature long RoI (market failures). Therefore the research and innovation activities need public support, as in USA or China.

Manufacturing is a key enabler for Europe's grand societal challenges

The Europe 2020 strategy is concerned not only with jobs but also showing how Europe has the capability to deliver sustainable and inclusive growth. Its concrete targets are:

1. Employment: 75 % of the 20–64 year-olds to be employed;
2. R & D/innovation: 3 % of the EU's GDP — public and private combined — to be invested in R & D/innovation;
3. Climate change/energy: greenhouse gas emissions 20 % — or even 30 %, if the conditions are right — lower than 1990; 20 % of energy from renewables; 20 % increase in energy efficiency;
4. Education: reducing school drop-out rates below 10 %; at least 40 % of 30–34 year-olds completing third-level education;
5. Poverty/social exclusion: at least 20 million fewer people in or at risk of poverty and social exclusion.

The European manufacturing industry is aiming at a fundamental impact on 'growth and jobs' which are a prerequisite for social sustainability, addressing the needs of citizens and the environment. Hence 'growth and jobs' are considered to be a major enabler for the achievement of all of the EU's 'grand societal challenges'.

In order to allow European manufacturing to have a significant impact in addressing major social-driven targets and challenges, an increase in joint government–industry investments in cross-disciplinary manufacturing research is vital. A critical mass of stakeholders and leadership at EU level are needed to go beyond the limited capacity of individual Member States. The EU needs a strong industrial R & D policy ensuring industrial competitiveness. To achieve the timely deployment in the EU of the new technologies, across sectors and also in SMEs, a contractual PPP is needed.

³ 'An introduction to mechanical engineering: Study on the competitiveness of the EU mechanical engineering industry within the framework contract of sectoral competitiveness studies — ENTR/06/054 — Final Report', page 203; (EU-10: Czech Republic, Denmark, Germany, Spain, Italy, Hungary, Netherlands, Austria, Poland, Slovak Republic).

Hence, the general objectives of the Factories of the Future PPP are to:

- increase EU industrial competitiveness and sustainability in a global world through R & I activities for the timely development of new knowledge-based production technologies and systems:
 - competitive and sustainable production plants;
 - industrial automation, machinery and robotics;
 - industrial software for design and plant management;
- promote EU 2020 targets of a smart, green and inclusive economy:
 - energy- and resource-efficient manufacturing processes;
 - socially sustainable, safe and attractive workplaces;
 - high-tech companies involved in innovative manufacturing;
- support EU industrial policy targets (EC industrial policy communication October 2012):
 - raising the share of manufacturing in EU GDP from 16 % to 20 % by 2020;
 - raising industrial investment in equipment from 6 % to 9 % by 2020;
 - ensuring technology transfer and training across manufacturing sectors;
- underpin EU trade and investment policy:
 - EU to remain the leading trade region in the world, keeping the share of EU trade in goods between 15–20 %.

The specific objectives of the Factories of the Future PPP are as follows:

- R & I to integrate and demonstrate innovative technologies for advanced manufacturing systems (40–50 new best practices):
 - 8–10 in high-tech manufacturing processes for both current and new materials or products, including 3D printing, nano- and microscale structuring;
 - 10–12 in adaptive and smart manufacturing equipment and systems, including mechatronics, robotics, photonics, logistic and monitoring systems;
 - 10–12 in ICT for resource-efficient factory design, data collection and management, to increase production performance through operation and planning optimisation;
 - 4–5 in collaborative and mobile enterprises, networked factories and dynamic supply chains, for locally adapted production;
 - 6–8 in human-centred manufacturing, enhancing the role of people in factories and designing the workplaces of the future;
 - 2–3 in customer-focused manufacturing, from product-process to innovative services.
- R & I leading towards environment-friendly manufacturing, with potentially:
 - reduction of energy consumption in manufacturing activities (up to 30 %);
 - less waste generated by manufacturing activities (up to 20 %);
 - less consumption of materials (up to 20 %).
- R & I to develop approaches to reverse the deindustrialisation of Europe:
 - 6–8 new types of high-skilled jobs to increase industrial commitment to stay in the EU;
 - innovation to raise industrial investment in equipment from 6 % to 9 % by 2020.

- R & I for social impact:
 - increase human achievements in future European manufacturing systems;
 - creating sustainable, safe and attractive workplaces for ‘Europe 2020’;
 - creating sustainable care and responsibility for employees and citizens in global supply chains;
 - bring a majority of manufacturing engineering graduates and doctorate holders into manufacturing employment and increase the opportunities for technician employment.
- R & I for promoting entrepreneurship:
 - foster the creation of technological-based companies around manufacturing of innovative products;
 - increase business R & D expenditure in manufacturing.

Enabling role of manufacturing

The Europe 2020 strategy underlines the role of ‘technology’ as the ultimate solution-provider for tackling the challenge of increasing Europe’s economic growth and job creation. It shows the way forward as investing in key enabling technologies, which will help innovative ideas to be turned into new products and services that create growth, high-skilled adding-value jobs, and help address European and global societal challenges.

Occupying a critical ‘enabling’ role, the manufacturing process is behind every high-value product or service, including (but not limited to) the products/services that rely on the photonics, nanotechnology, advanced materials, micro/nano-electronics and biotechnology referred to, along with advanced manufacturing systems, as key enabling technologies (KETs)⁴.

The application of technological innovations in competitively marketable goods and services is enabled by manufacturing. Advanced manufacturing systems play a critical part in making KETs and new products competitive, affordable and accessible; multiplying their societal and economic benefits. Products of high value and superior features cannot generate any value for society and the economy if they are not affordable or if they are late into the market. Advanced manufacturing enables a cost-effective, resource-efficient and timely production and commercialisation.

Manufacturing is also essential for realising all future products related to societal challenges (e.g. energy-related equipment, health products, transport, etc.).

Europe has to be at the forefront in manufacturing to keep its competitive edge

A society creates value by mining natural resources, growing food, manufacturing products or delivering services. A society like Europe is not natural resource rich, and has maximised its food production. Service delivery alone has a limited potential in terms of employment and has less productivity improvement options than manufacturing has shown. Therefore

⁴ High Level Expert Group on Key Enabling Technologies, Final Report, June 2011.

manufacturing and improvements in manufacturing are essential for Europe to generate value for its people, buy the natural resources it needs, maintain the welfare of its people and protect its environment. Although Europe has lost market share in the total world manufacturing volume to Asia, it is still leading in the 'factories of the future' field and the equipment and systems needed to run such factories. Producing innovative products addressing grand challenges will be a major issue for the future and manufacturing will play a key role in this.

Industry and its partners are committed to the public-private partnership (PPP) model

The Factories of the Future PPP, as well as Horizon 2020 itself, requires a critical mass of stakeholders and clear industrial commitment. This roadmap presents an implementation going beyond the capacity of Member States, requiring a pan-European approach with a critical mass of stakeholders. Substantial, long-term commitment and the leadership of industrial companies and associations are required for implementation.

The commitment of industry to the 'Factories of the Future' PPP is already evident in the successful implementation of the PPP to date, the substantial increase of industrial involvement (including SME) in comparison with other framework programmes (FPs), the 'PPP Declaration of Commitment' signed at Aarhus (June 2012) and the targets pursued by this roadmap.

Megatrends and the response of the manufacturing industry

In all manufacturing sectors, megatrends⁵ have considerable impact, driving structural changes. A new global socioeconomic logic must be embraced by Europe for its own future prosperity. Under this logic Europe will address economic success, the welfare of its people and contributes to the preservation of the environment and resources.

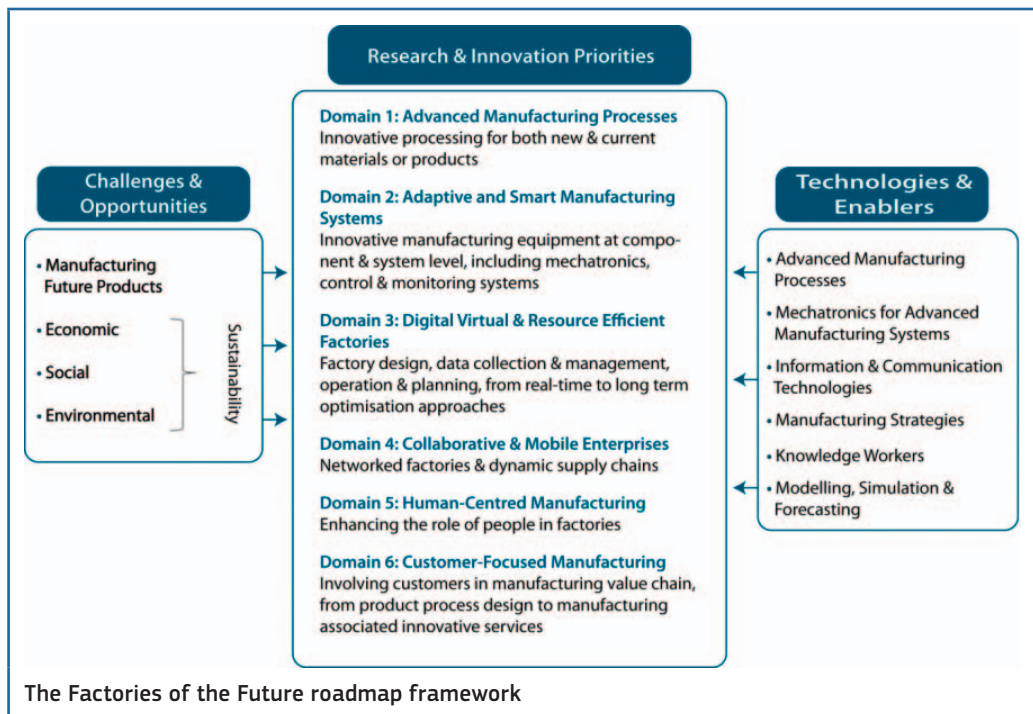
The Europe 2020 strategy utilises this logic in addressing the European grand challenges (climate change, energy and food security, health and an ageing population). Manufacturing enables many of these at a scale that contributes to economic wealth whilst minimising environmental impact and creating a sustainable society. In response to these megatrends and in line with the Europe 2020 strategy, European manufacturing will undergo structural transformations towards sustainable competitiveness.

Overall, the achievement of the identified transformations requires a coordinated research and innovation effort, where manufacturing challenges and opportunities are addressed by deploying successively the following set of technologies and enablers: advanced manufacturing processes and technologies including photonics, mechatronics for advanced manufacturing systems including robotics, information and communication technologies (ICT)⁶, manufacturing strategies, knowledge-workers and modelling, simulation and forecasting methods and tools.

⁵ Source: Roland Berger strategy consultants based on World Bank, OECD, IMF, Unctad, EC, UNEP, Unesco statistics and others — also related to EU documents (EU2020, Lund declaration).

⁶ ICT for manufacturing, The ActionPlanT Roadmap for Manufacturing 2.0.

Addressing the challenges and opportunities with the right technologies and enablers along the lines of the required transformations (= the research innovation domains) constitutes the framework of the Factories of the Future roadmap.



The Factories of the Future PPP identifies and realises the transformations by pursuing a set of research priorities along six research and innovation domains. Each of these domains embodies a particular aspect of the required transformations towards the factories of the future. The research and innovation activities undertaken within the domains should focus on a concrete and measurable set of targets, described as the manufacturing challenges and opportunities. Addressing these challenges and opportunities is at the core of what the Factories of the Future PPP is determined to achieve.

The realisation of the research and innovation objectives of the Factories of the Future PPP will require a public funding budget of EUR 500 million/year which the private sector is committed to match with equivalent contribution in kind. The overall resulting size of the Factories of the Future programme within Horizon 2020 will then become EUR 7 billion.

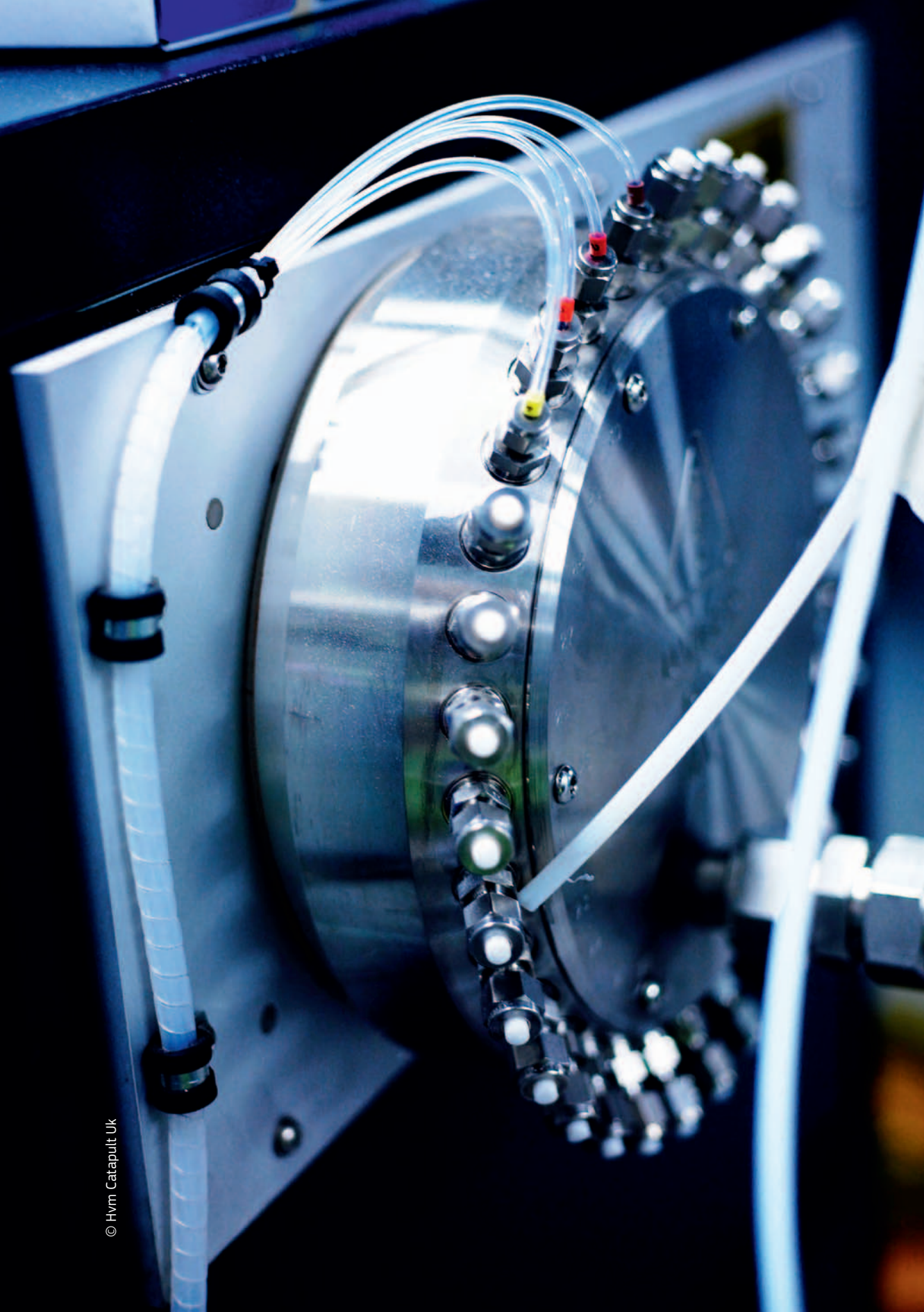
Impact through a challenge-oriented research and innovation programme, through dissemination and demonstration

R & D investments only become economically and socially relevant when they generate value for companies and society, namely via the creation and exploitation of new products, services, business models and processes, the development of new knowledge and skills and also the

creation of new and better jobs. These objectives are particularly relevant in an industry-led initiative such as the Factories of the Future PPP and when public funds are involved.

The challenge for the next period is to take this trend even further, creating the conditions for projects and consortia to bring their results to a pre-commercial/exploitation stage, namely by developing pre-series, installing pilot production lines, etc. The extension of the programmes' scope will call for more complete consortia (capable of gathering all the necessary resources and competences). The funding needs will also increase significantly and that, matched with the fact that final results (or, at least, some of them) will be more region, sector or company specific, will require a new combination of different funding sources, both public and private, that could include cohesion funds, risk capital, etc. It is also important to stress that, since the Factories of the Future PPP targets the development of horizontal and enabling technologies, research projects' results need to be disseminated across the entire industry in Europe and not only among the sectors and regions directly involved. This unleashes their full potential impact by promoting their exploitation in other applications. Existing cluster organisations and open innovation concepts and tools can be used to support these objectives.

Monitoring and assessment of the progress towards achieving the desired effects and expected impact of the Factories of the Future initiative is critical. A first set of key performance indicators (KPIs) is proposed and will be further detailed throughout the refinement of the roadmap. The monitoring and assessment of progress in terms of KPIs on project level and in terms of the overall performance of the Factories of the Future PPP will be supported by a database and web application that will also serve as a dissemination portal on project objectives, participants, results and impact. It will inspire the manufacturing community to take up innovation a step further by building on the programme's results.



Part I: Vision 2030

1 The importance of manufacturing

Manufacturing demonstrates a huge potential to generate wealth and to create high-quality and highly skilled jobs. Around one in ten (9.8 %) of all enterprises in the EU-27's non-financial business economy were classified as manufacturing in 2009, a total of 2.0 million enterprises. The manufacturing sector employed 31 million persons in 2009, generated EUR 5 812 billion of turnover and EUR 1 400 billion of value added. In 2010 turnover increased to EUR 6.4000 billion. By these measures, manufacturing was the second largest of the NACE sections within the EU-27's non-financial business economy in terms of its contribution to employment (22.8 %) and the largest contributor to non-financial business economy value added⁷, accounting for one quarter (25.0 %) of the total (*source: Eurostat*)⁸. For example, in 2008, manufacturing jobs and jobs directly depending on manufacturing represented 36.7 % of the overall employment in Germany.

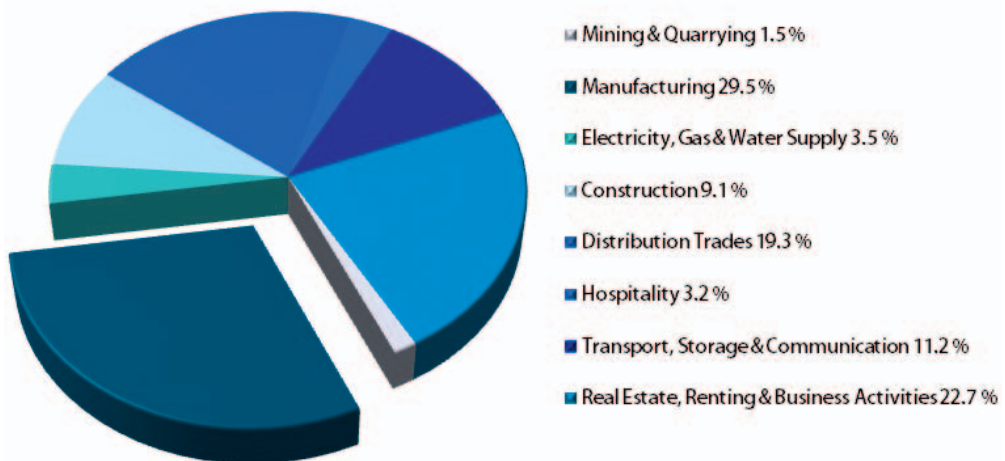
⁷ Value added = revenue minus outside purchases.

⁸ Manufacturing statistics — NACE Rev. 2. (http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Manufacturing_statistics_-_NACE_Rev_2).

	Value
Main indicators	
Number of enterprises (1 000)	2 039
Number of persons employed (1 000)	30 668
Turnover (EUR million)	5 812 027
Purchases of goods and services (EUR million)	4 282 582
Personnel costs (EUR million)	989 022
Value added (EUR million)	1 396 136
Gross operating surplus (EUR million)	407 114
Share in non-financial business economy total (%)	
Number of enterprises	9.8
Number of persons employed (1)	22.9
Value added (1)	25.0
Derived indicators	
Apparent labour productivity (EUR 1 000 per head)	46
Average personnel costs (EUR 1 000 per head)	34.5
Wage adjusted labour productivity (%)	132.1
Gross operating rate (%)	7.0

Key indicators (manufacturing)⁹

On average, EUR 45 161 of value added in manufacturing was generated by each person employed. Total investment by the EU-27 manufacturing sector was valued at EUR 262 billion in 2006, equivalent to almost 14 % of the manufacturing sector's value added^{10, 11, 12}.

Breakdown of non-financial business economy — value added, EU-27 (2007)¹³

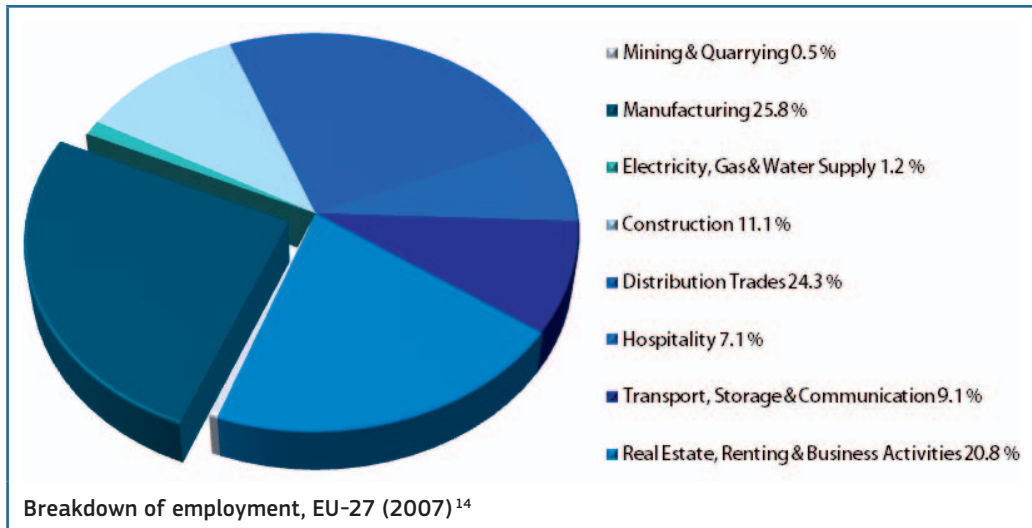
⁹ NACE Section C, EU-27, 2009.

¹⁰ Yearbook 2011, Eurostat.

¹¹ Statistical Classification of Economic Activities in the European Community, NACE.

¹² Statistisches Bundesamt, Stand 01/2010.

¹³ Source: Eurostat.



European manufacturing is a dominant part of international trade:

The EU exports consist mainly of manufactured products: their share has annually been more than 80 % of total EU exports. In 2011, exports of ‘machinery and vehicles’ and ‘other manufactured goods’ together reached EUR 1 000 billion, with an increase of about 40 % in comparison with the lower level of 2009.

The surplus in trade of manufactured goods reached a peak of EUR 264 billion in 2011, more than double the surplus registered in 2006.

Indicatively, the European mechanical engineering sector has grown steadily from 1990 until 2007 and represents 9.78 % of the value of EU-27 industrial production. Its size makes the EU the largest producer of mechanical engineering equipment in the world, clearly surpassing the US and Japan. The value of global trade with mechanical engineering products came up to EUR 539 billion in 2010. The EU is by far in the lead with a share of 37 % and exports have increased by 43 % in the last 3 years. Though imports have also increased, the trade balance has been positive (EUR 115 101 million in 2007), only taking a negative turn at the end of 2008 as a result of the global economic crisis. The total exports of machinery represent 42 % of total mechanical engineering production. Internal consumption of machinery rose by 14 % in 2007, from EUR 337 475 million to EUR 383 347 million¹⁵.

Manufacturing activity is important for SMEs: SMEs are the backbone of manufacturing industry in Europe. Micro, small and medium enterprises provide around 45 % of the value added by manufacturing while they provide around 59 % of manufacturing employment¹⁶.

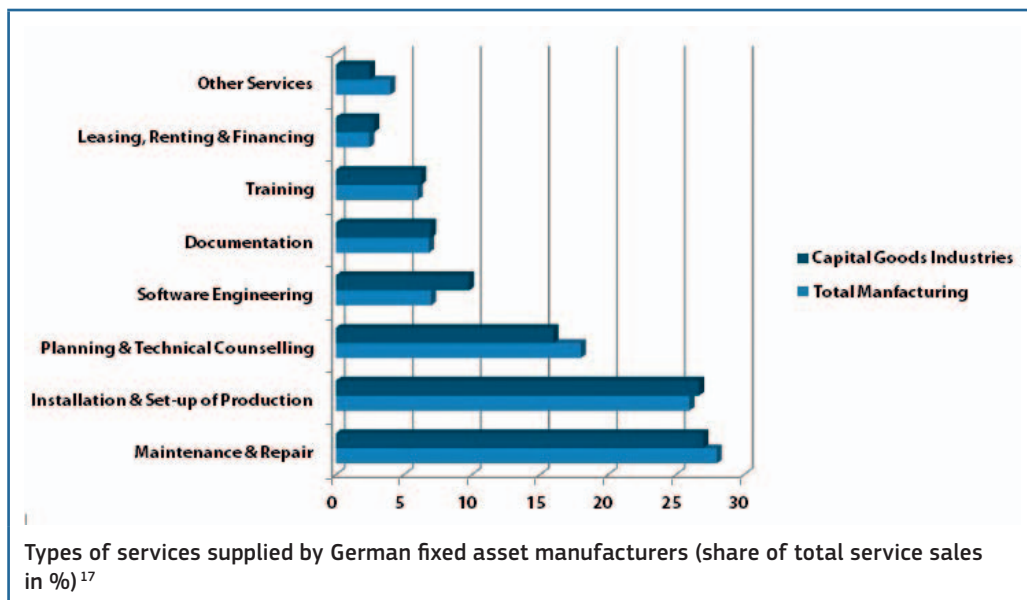
¹⁴ Source: Eurostat.

¹⁵ Eurostat, ‘Statistics in Focus, Industry, trade and services’, 62/2009. [Ifi Institute, Cambridge Econometrics, Danish Technological Institute, Study on the Competitiveness of the EU Mechanical Engineering Industry, 2012 [External and intra-European Union trade, Monthly statistics — Issue number 12/2011].

¹⁶ Eurostat, Statistics in Focus, Industry, trade and services, 62/2009.

Manufacturing is critical for emerging markets: New markets driven by advances in science and innovation will revolutionise Europe's capability to expand manufacturing across traditional and new industries.

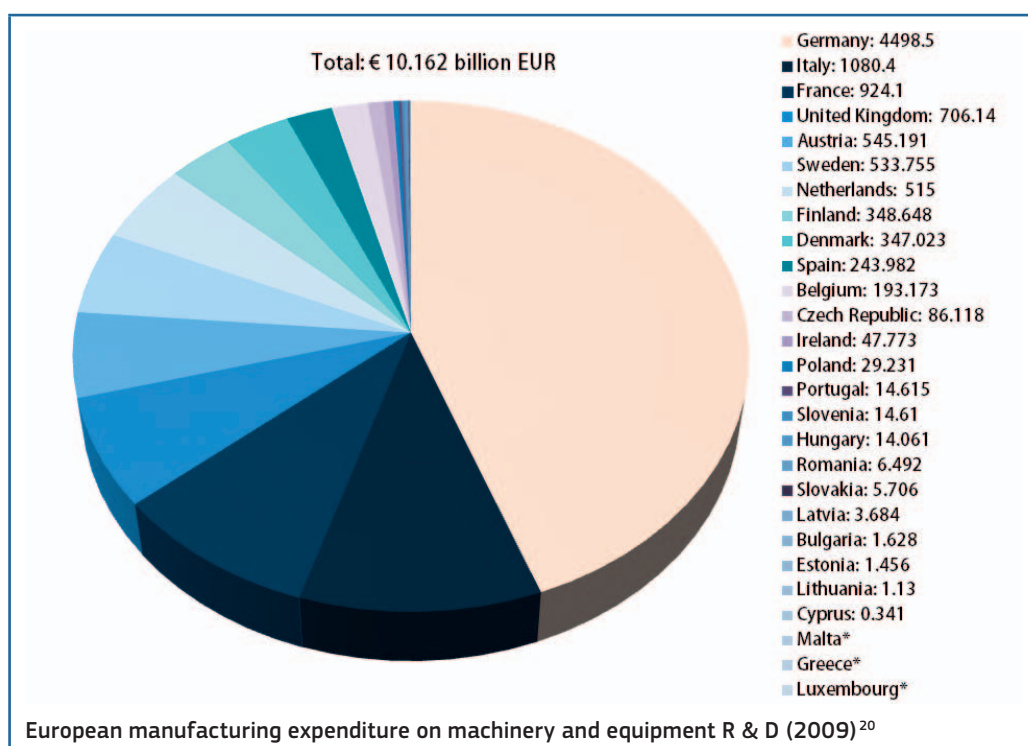
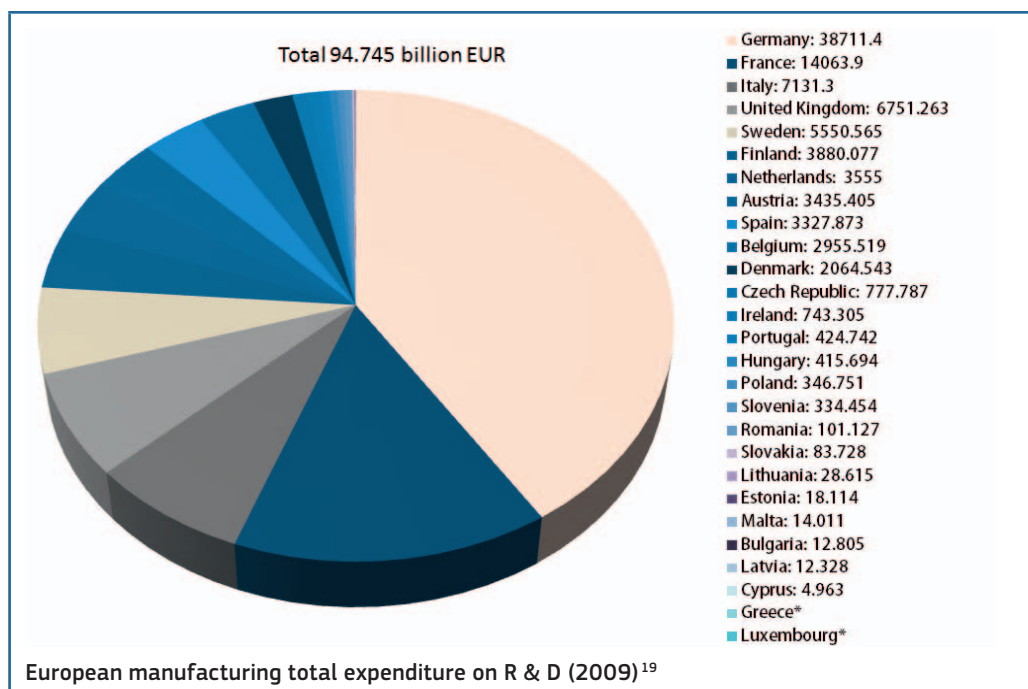
Manufacturing and services are linked with each other: Notably in the machinery sector which provides increasingly sophisticated machines and comprehensive production systems, installation, set-up and training of operators is an integral part of the business.



Manufacturing is an RD & I intensive activity: In 2006, the R & D expenditure in the mechanical engineering sector in the EU-10 alone was \$ 8 323 million ¹⁸. In 2007, the manufacturing sector received the greatest share of business enterprise R & D expenditure in most of the EU-27 countries. This was notably the case in Germany, Slovenia and Finland, where 88.7 %, 88.2 % and 80.0 % respectively of R & D expenditure by the business enterprise sector (BES) went on manufacturing. The overall Europe 2020 headline indicator GERD (Gross expenditure on research and development) % of GDP ('R & D intensity') in 2011 is at 2.03 % as compared with 2.01 % in 2010, while the Europe 2020 target is 3 %. Across all industries R & D intensity was 3.5 % in 2009 worldwide. At the same time, R & D intensity of mechanical engineering in Europe was 3.6 whereas in USA and Japan it was 3.2 % and 3.0 % respectively. This indicates that in the EU, mechanical engineering is of higher importance for overall technological performance than in the US and Japan where the sector figure was below total industries. However, the R & D costs and risks involved to keep EU industry competitive and sustainable are too high and feature long RoI (market failures). Therefore the research and innovation activities need public support, as in USA or China.

¹⁷ Federal Statistics Bureau of Germany; calculations by Ifo.

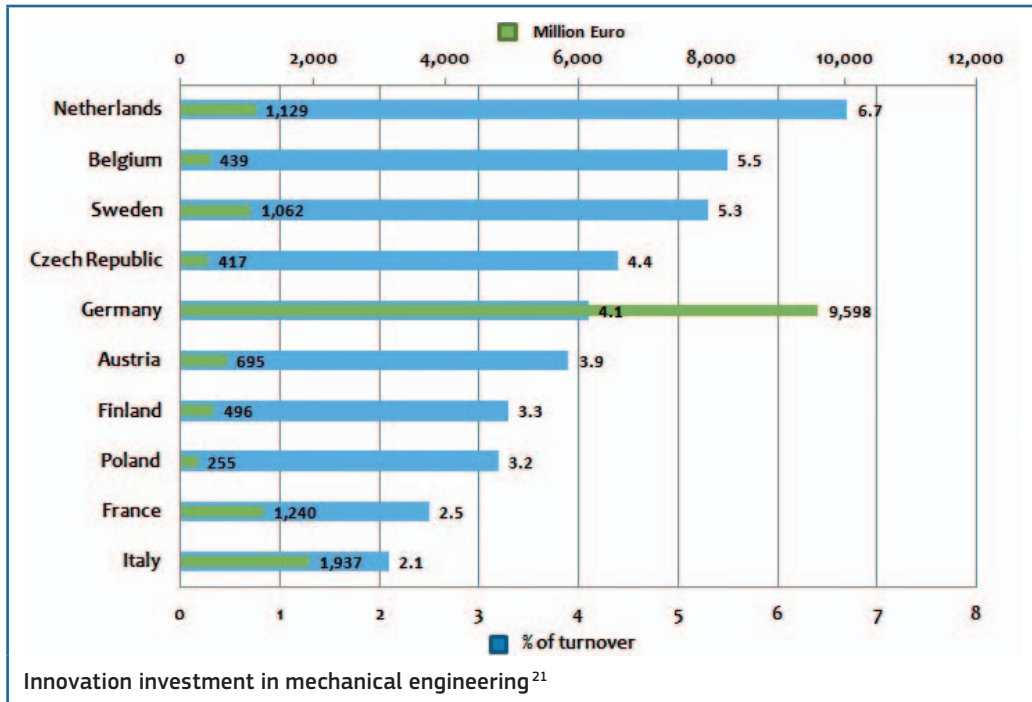
¹⁸ 'An introduction to mechanical engineering: Study on the competitiveness of the EU mechanical engineering industry within the framework contract of sectoral competitiveness studies' — ENTR/06/054 — Final Report.



¹⁹ Business Enterprise R & D Expenditure (BERD) by Economic Activity 2009 (NACE Rev. 2).

²⁰ Business Enterprise R & D Expenditure (BERD) by Economic Activity 2009 (NACE Rev. 2).

Manufacturing is an indispensable element of the innovation chain: Every high-value product or service has a manufacturing process behind it. Manufacturing enables technological innovations to be applied in goods and services, which are marketable in the marketplace and is key to exploiting KETs and making new products affordable and accessible so as to multiply their societal and economic benefits and achieve the desired impacts. Location matters since 'innovation' is not linear, the ability to innovate greatly benefits from co-location of manufacturing and manufacturing-related R & D activities, including product research and development processes.



In the business enterprise sector manufacturing accounted for the highest share of researchers in most EU Member States. In 2008, 14.1 % of all EU-27 tertiary students were participating in engineering, manufacturing and construction education. In 2008, 39.8 % of enterprises in the EU-27 were considered innovative in terms of technological innovation²². In most countries, the proportion of innovative enterprises was generally higher in manufacturing than in services. In 2009, 2.4 million people were employed in the high-tech manufacturing sector in the EU-27²³.

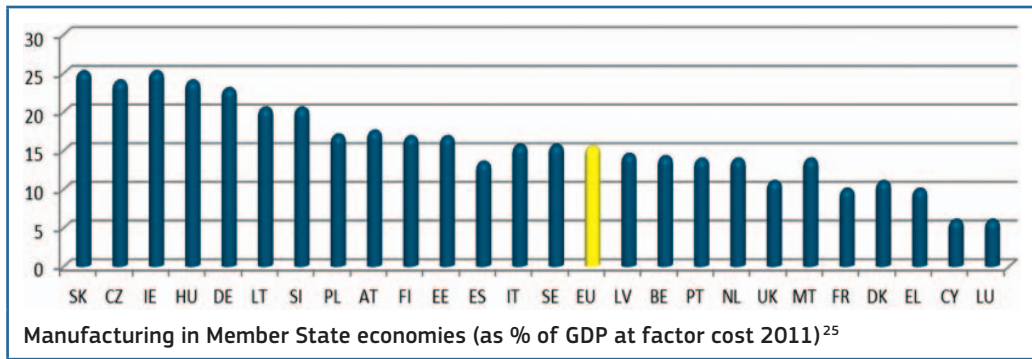
Manufacturing is spread throughout Europe: Manufacturing provides jobs and wealth in each and every Member State and region of the EU, and economic activity is highly interlinked. The European dimension is crucial and the potential of EU-coordinated action for improving competitiveness is evident.

²¹ Eurostat, CIS6.

²² 'Study on the competitiveness of the EU mechanical engineering industry', Ifo Institute, Cambridge Econometrics and Danish Technological Institute, 2012.

²³ Science, technology and innovation in Europe, Eurostat Pocketbook, 2011.

The following graph shows the importance of manufacturing in today's economies of EU Member States (as % of GDP at factor costs in 2011²⁴).



²⁴ Eurostat, 2011.

²⁵ Eurostat, 2011 (LU 2010, Statec).

2 Manufacturing is a key enabler for Europe's grand societal challenges

2.1 The need for a manufacturing PPP at EU level

The preface of the Europe 2020 strategy states: 'It's about more jobs and better lives. It shows how Europe has the capability to deliver smart, sustainable and inclusive growth, to find the path to create new jobs and to offer a sense of direction to our societies ...' (José Manuel Barroso, Preface to 'Europe 2020, A European Strategy for Smart, Sustainable and Inclusive Growth'²⁶). The concrete targets are:

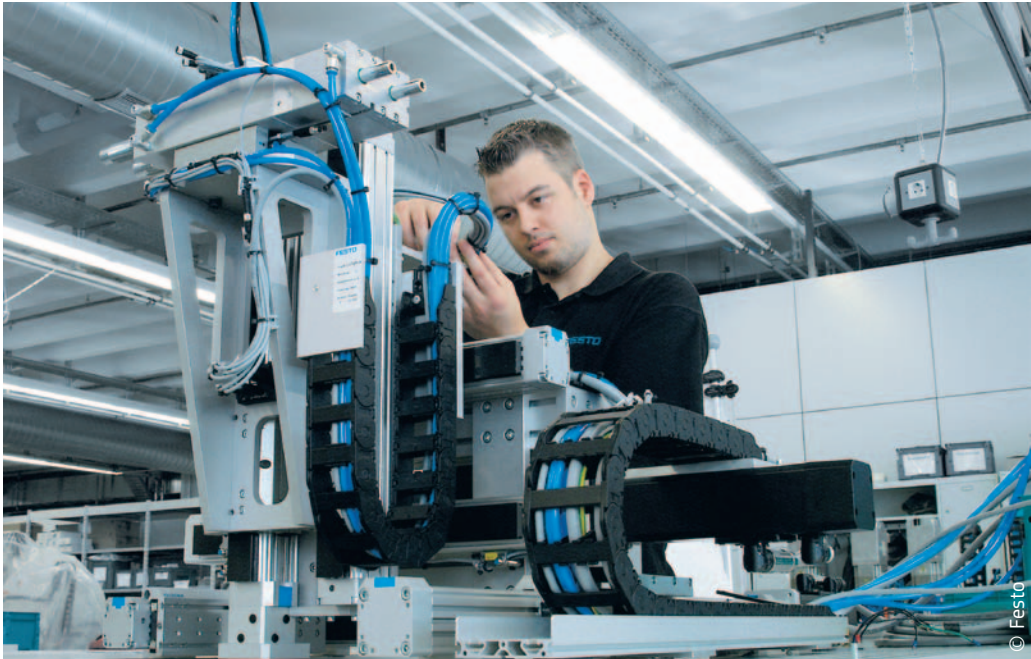
1. Employment: 75 % of the 20–64 year-olds to be employed;
2. R & D/innovation: 3 % of the EU's GDP — public and private combined — to be invested in R & D/innovation);
3. Climate change/energy: greenhouse gas emissions 20 % — or even 30 %, if the conditions are right — lower than 1990; 20 % of energy from renewables; 20 % increase in energy efficiency;
4. Education: reducing school drop-out rates below 10 %; at least 40 % of 30–34 year-olds completing third-level education;
5. Poverty/social exclusion: at least 20 million fewer people in or at risk of poverty and social exclusion.

Fully in line with this vision, the European manufacturing industry primarily aims at a fundamental impact on 'growth and jobs'. Growth and jobs are a prerequisite for a societal sustainability that addresses the needs of citizens and the environment, and as such are considered a major enabler to the achievement of all of the EU's 'grand societal challenges'.

Increasing joint government–industry investments on cross-disciplinary manufacturing research would allow significant impact in terms of addressing major social-driven targets and challenges for European manufacturing. A critical mass of stakeholders and leadership at EU level are needed to go beyond the limited capacity of individual Member States.

The EU needs a strong industrial R & D policy ensuring industrial competitiveness. The complexity of technologies and challenges and the need for a long-term horizon for investment in innovation require more than public support to individual projects. To achieve the timely deployment in the EU of the new technologies, across sectors and also in SMEs, a broad contractual PPP is needed.

²⁶ Europe 2020, A European strategy for smart, sustainable and inclusive growth, COM(2010) 2020.



2.2 General and specific objectives of the Factories of the Future PPP

Hence, the general objectives of the Factories of the Future PPP are to:

- increase EU industrial competitiveness and sustainability in a global world through R & I activities for the timely development of new knowledge-based production technologies and systems:
 - competitive and sustainable production plants;
 - industrial automation, machinery and robotics;
 - industrial software for design and plant management;
- promote EU 2020 targets of a smart, green and inclusive economy:
 - energy- and resource-efficient manufacturing processes;
 - socially sustainable, safe and attractive workplaces;
 - high-tech companies involved in innovative manufacturing;
- support EU industrial policy targets (EC industrial policy communication October 2012):
 - raising the share of manufacturing in EU GDP from 16 % to 20 % by 2020;
 - raising industrial investment in equipment from 6 % to 9 % by 2020;
 - ensuring technology transfer and training across manufacturing sectors;
- underpin EU trade and investment policy:
 - EU to remain the leading trade region in the world, keeping the share of EU trade in goods between 15–20 %.

The specific objectives of the Factories of the Future PPP are as follows:

- R & I to integrate and demonstrate innovative technologies for advanced manufacturing systems (40–50 new best practices):
 - 8–10 in high-tech manufacturing processes for both current and new materials or products, including 3D printing, nano- and microscale structuring;
 - 10–12 in adaptive and smart manufacturing equipment and systems, including mechatronics, robotics, photonics, logistic and monitoring systems;
 - 10–12 in ICT for resource-efficient factory design, data collection and management, to increase production performance through operation and planning optimisation;
 - 4–5 in collaborative and mobile enterprises, networked factories and dynamic supply chains, for locally adapted production;
 - 6–8 in human-centred manufacturing, enhancing the role of people in factories and designing the workplaces of the future;
 - 2–3 in customer-focused manufacturing, from product-process to innovative services.
- R & I leading towards environment-friendly manufacturing, with potentially:
 - reduction of energy consumption in manufacturing activities (up to 30 %);
 - less waste generated by manufacturing activities (up to 20 %);
 - less consumption of materials (up to 20 %).
- R & I to develop approaches to reverse the deindustrialisation of Europe:
 - 6–8 new types of high-skilled jobs to increase industrial commitment to stay in the EU;
 - innovation to raise industrial investment in equipment from 6 % to 9 % by 2020.
- R & I for social impact:
 - increasing human achievements in future European manufacturing systems;
 - creating sustainable, safe and attractive workplaces for ‘Europe 2020’;
 - creating sustainable care and responsibility for employees and citizens in global supply chains;
 - bringing a majority of manufacturing engineering graduates and doctorate holders into manufacturing employment and increase the opportunities for technician employment.
- R & I for promoting entrepreneurship:
 - foster the creation of technological-based companies around manufacturing of innovative products;
 - increase business R & D expenditure in manufacturing.

2.3 Enabling role of manufacturing

The Europe 2020 strategy highlights the short- and long-term challenges Europe has to tackle. The immediate challenge is putting the European economy back on an upward path of growth and job creation, whilst long-term global challenges comprise, inter alia, globalisation, pressure on resources and an ageing population. The Europe 2020 strategy underlines the role of ‘technology’ as the ultimate solution-provider for tackling these challenges. It shows the way

forward as investing in key enabling technologies, which will help innovative ideas to be turned into new products and services that create growth, highly skilled value-adding jobs, and help address European and global societal challenges.

It should be kept in mind that today every high-value product or service has a manufacturing process behind it. This includes, but is not limited to, the products/services that rely on the photonics, nanotechnology, advanced materials, micro/nano-electronics and biotechnology referred to, along with the advanced manufacturing systems, as key enabling technologies (KETs)²⁷.

Manufacturing enables technological innovations to be applied in goods and services, which are competitively marketable in the marketplace. Advanced manufacturing systems have a critical role in making key enabling technologies and new products competitive, affordable and accessible so as to multiply their societal and economic benefits. Products of high value and with superior features cannot generate any value for society and the economy if they are not affordable or if they are not put into the market in time. Advanced manufacturing not only allows the turning of technological achievements into products and services, but it also enables a cost-effective, resource-efficient and timely production and commercialisation.

Manufacturing research is very relevant not only for European competitiveness, growth and jobs but also for realising all future products related to societal challenges (transport systems, energy-related equipment, health-related products and equipment, impact on environment, etc.).

2.4 Europe has to be at the forefront in manufacturing to keep its competitive edge

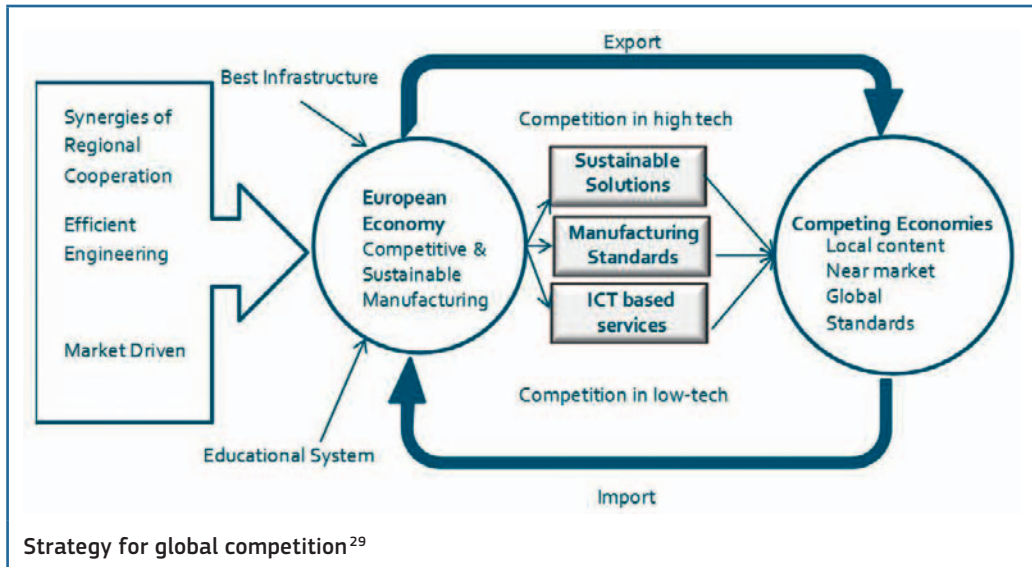
A society creates value by mining natural resources, growing food, manufacturing products or delivering services. A society like Europe is not natural resource rich, and has maximised its food production. Service delivery alone has a limited potential in terms of employment and has less productivity improvement options than manufacturing has shown. Therefore manufacturing and improvements in manufacturing are vital for Europe to generate value for its people, buy the natural resources it needs, maintain the welfare of its people and protect its environment.

Two hundred years ago it was Europe where the greatest concentration of manufacturing of goods in factories, as a concentration of value-creating activities, was to be found. Although Europe has lost market share in the total world manufacturing volume to Asia, it is still leading in the factories of the future field and in the equipment and systems needed to run such factories²⁸. But Europe cannot afford to lose its manufacturing capability. The trade deficit in the USA and their uphill battle to gain back USA-based manufacturing is a good example. Therefore, European manufacturing has to increase and retain its global competitiveness.

²⁷ High-Level Expert Group on Key Enabling Technologies, Final Report, June 2011.

²⁸ The majority of high-volume semiconductor factories are located outside Europe. Semiconductor fabs become heavily robotised and only result in jobs during the construction of the fab. Europe is leading in the equipment for such fabs. Semiconductor equipment building cannot be robotised and, as a result, Europe has 100 000 jobs in equipment building for this industry.

Producing innovative products that address grand challenges will be a major issue for the future and manufacturing will play a key role in this. It is crucial that the innovation capacity and competitiveness of EU industry is developed in order to ensure that the EU will be able to take a significant share of this increasing global market. The EU 'balance of trade' can only be maintained by a globally competitive industrial sector with respect to both cost and value.



The manufacturing industry in the EU should be able to command competitive value chains from research and development (R & D) to volume production, in some areas, in order to stay competitive. Manufacturing activities themselves generate jobs and wealth in the geographical space where they are performed.

The purpose of manufacturing is to create value while the factory may be defined as the place where society concentrates its repetitive value creation process. The ability to innovate and compete in the global economy greatly benefits from the co-location of manufacturing and manufacturing-related R & D activities, including product research and development processes (since innovation is not linear). The loss of these activities would undermine the capacity to invent, innovate, and compete in global markets. Europe cannot live by R & D alone, because if further links in the value chain are lost this will also take away R & D sooner or later.

Without competitive replication technologies, the deployment of better products will be limited and the expected impact on challenges will not be achieved. To be the first to apply innovations and to put products on the market, Europe needs to have factories of the future to make this new equipment to manufacture these new products at the right time and price.

²⁹ Manufacturing 2030.

3 Manufacturing 2030 Vision and the strategic objectives of the FoF PPP

3.1 Megatrends and manufacturing

Megatrends³⁰ have considerable impact and drive structural changes in nearly all manufacturing sectors. These megatrends can be identified as:

- changing demographics (growing world population, ageing societies, increasing urbanisation);
- globalisation and future markets (BRIC and beyond);
- scarcity of resources (energy, water, other commodities);
- the challenge of climate change (increasing CO₂, global warming, ecosystem at risk);
- dynamic technology and innovation (ICT and virtualisation, technology diffusion, the age of life science, ubiquitous connectivity, sensing and digitalisation);
- global knowledge society (know-how base, gender gap, war for talent, multiplication of data and information);
- mass customisation (personalised customisation);
- sharing global responsibility (shift to global cooperation, growing power of NGOs, increasing philanthropy).

Because of these megatrends, Europe has to embrace a new logic of global socioeconomic sustainability, in which it addresses economic success, the welfare of its population and contributes to the preservation of the environment and resources.

The rise of transport costs, the need for higher efficiency and productivity, the customer and user demand for greener products, the higher instability of raw material and energy prices and the shortening of the lead-time for production will push for a more critical assessment of the delocalisation strategy towards low-cost countries. Service-led personalised products will require a new paradigm for western countries' reindustrialisation (known as Globalisation 2.0), moving back manufacturing of selected products.

The Europe 2020 strategy applies this logic in addressing the European grand challenges (climate change, energy security, food security, health, ageing population) and puts forward concrete targets (see section 2).

Manufacturing enables many of the above, and does so at scale to contribute to economic wealth, whilst minimising impact on the environment and creating a sustainable society for social inclusion.

³⁰ Source: Roland Berger strategy consultants based on World Bank, OECD, IMF, Unctad, EC, UNEP, Unesco statistics and others — also related to EU documents (EU2020, Lund declaration).

3.2 The long-term direction: Manufacturing vision 2030

Four long-term paradigms will guide the transformations that European manufacturing needs to undergo:

Factory and nature -> green/sustainable

- Lowest resource consumption energy — lean, clean, green
- Closed loops for products/production and scarce resources
- Sustainability in material, production processes/workers

Factory as a good neighbour -> close to the worker and the customer

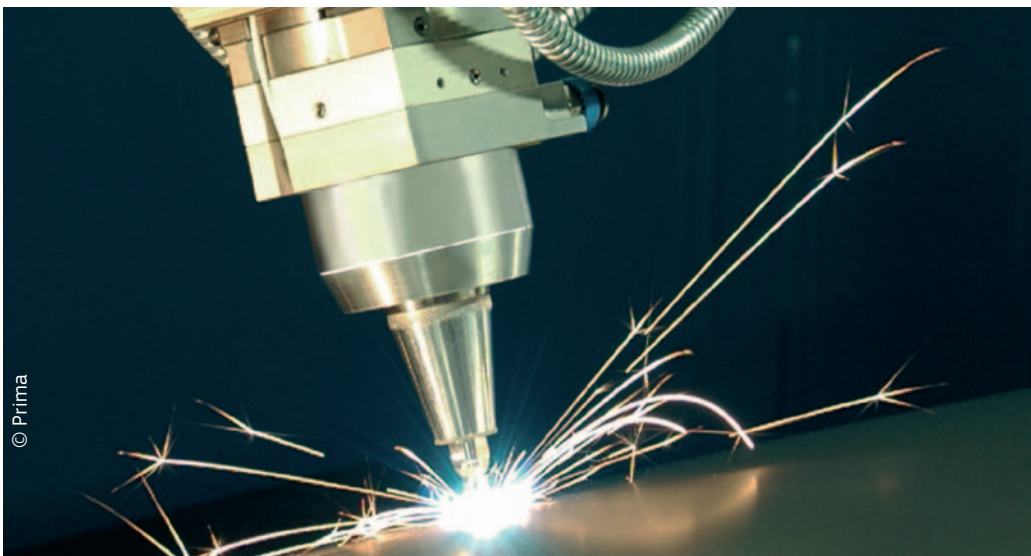
- Manufacturing close to people (in cities/metropolitan areas)
- Factory integrated and accepted in the living environment
- Event-oriented production/integration of customers

Factories in the value chain -> collaborative

- Strive for highly competitive distributed manufacturing (flexible, responsive, high speed of change)
- European production system: design-oriented products, mass customised products
- Integration of the product and process engineering — agile and demand driven
Mastering the collaboration from simple to sophisticated products in the value chain

Factory and humans -> human centred

- Human-oriented interfaces for workers: process-oriented simulation and visualisation
- Products and work for different type of skilled and aged labour, education and training with IT support
- Regional balance: work conditions in line with the way of life, flexible time- and wage-systems
- Knowledge development, management and capitalisation



3.3 Transformations in response to megatrends and following the Manufacturing 2030 vision

In response to the megatrends European manufacturing sectors need to undergo innovation-driven transformations towards the Manufacturing 2030 vision.

The Factories of the Future PPP identifies and realises these transformations by pursuing a set of research priorities along the following research and innovation domains:

- **advanced manufacturing processes**
- **adaptive and smart manufacturing systems**
- **digital, virtual and resource-efficient factories**
- **collaborative and mobile enterprises**
- **human-centred manufacturing**
- **customer-focused manufacturing.**

Each of these domains embodies a particular aspect of the required transformations towards the factories of the future.

The research and innovation activities undertaken within the domains should focus on a concrete and measurable set of targets, described as the following manufacturing challenges and opportunities:

- **Manufacturing the products of the future:** Addressing the ever-changing needs of society and offering the potential of opening new markets.
- **Economic sustainability** of manufacturing: Combining high performance and quality with cost-effective productivity, realising **reconfigurable, adaptive and evolving factories** capable of small-scale production in an economically viable way.
- **Social sustainability** of manufacturing: Integrating human skills with technology
- **Environmental sustainability** of manufacturing: Reducing resource consumption and waste generation.

Addressing these challenges and opportunities is at the core of what the Factories of the Future PPP is determined to achieve.

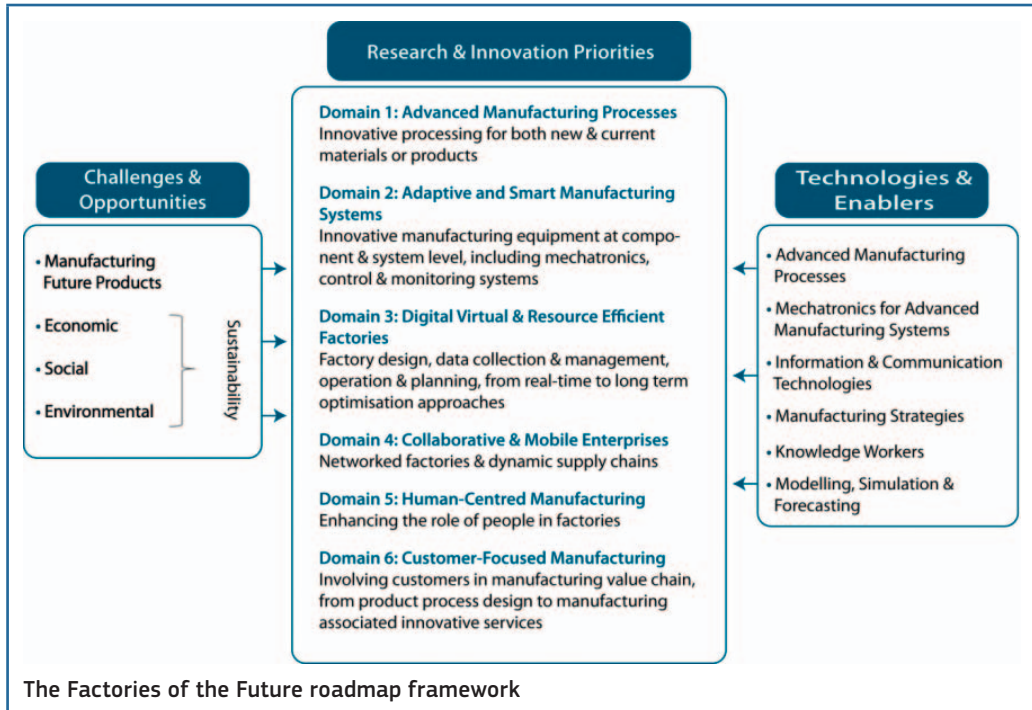
Overall, the achievement of the identified transformations requires a coordinated research and innovation effort, where manufacturing challenges and opportunities are addressed by deploying successively the following set of technologies and enablers:

- **advanced manufacturing processes and technologies**, including photonics;
- **mechatronics for advanced manufacturing systems**, including robotics;
- **information and communication technologies (ICT)**³¹;
- **manufacturing strategies**;

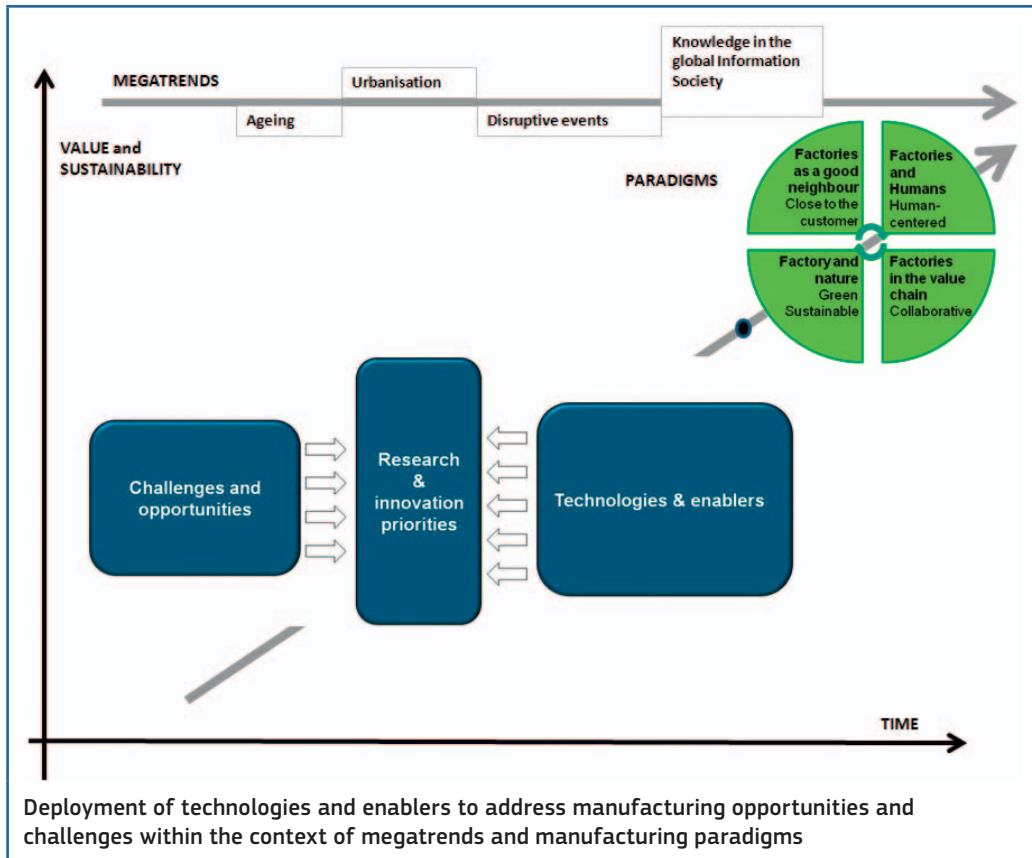
³¹ ICT for manufacturing, The ActionPlanT Roadmap for Manufacturing 2.0.

- knowledge-workers;
- modelling, simulation and forecasting methods and tools.

Addressing the challenges and opportunities with the right technologies and enablers along the lines of the required transformations (= the research innovation domains) constitutes the framework of this Factories of the Future roadmap. In part II of this roadmap, this framework is further developed.



The FoF roadmap framework integrates the Manufacturing 2030 paradigms and leads the way to concrete progress in response to European challenges, policies and megatrends.



4 Commitment of industry and their partners

4.1 Track record of the European manufacturing community

The Manufuture/EFFRA communities have a successful track record of fruitful cooperation and synergies with the European Commission (EC).

The European Technology Platform on Future Manufacturing Technologies (Manufuture ETP) was launched in 2004. Its mission is to define and implement research and innovation strategies capable of speeding up the rate of industrial transformation in Europe, securing high value-adding employment and winning a major share of world manufacturing output in the future knowledge-driven economy.

Over 100 organisations, from more than 20 countries, are directly and actively engaged in the ETP, including large original equipment manufacturers (OEMs), SMEs, industrial associations, research institutes, universities and national authorities. Under the ETP's umbrella, 28 Manufuture national and regional technology platforms (NRTPs) are active with more than 1 800 member organisations around Europe.

The European Factories of the Future Research Association (EFFRA) was launched by Manufuture ETP and industry associations in 2009. EFFRA's key objective is to promote pre-competitive research on production technologies within the 'European Research Area' (by engaging in the Factories of the Future (FoF) public-private partnership (PPP) with the European Union. Both Manufuture and EFFRA are horizontal initiatives and have been open from the very beginning to other European technology platforms with stakes in manufacturing in a very broad sense.

The Factories of the Future PPP is one of three PPPs included in the European Economic Recovery Plan. Its objective is to help European manufacturing enterprises, in particular SMEs, to adapt to global competitive pressures by improving the technological base of EU manufacturing across a broad range of sectors. The European Commission and the Manufuture/EFFRA communities have engaged in this partnership for jointly developing and implementing a research programme of some EUR 1.2 billion to support manufacturing industry in the development of new and sustainable technologies.

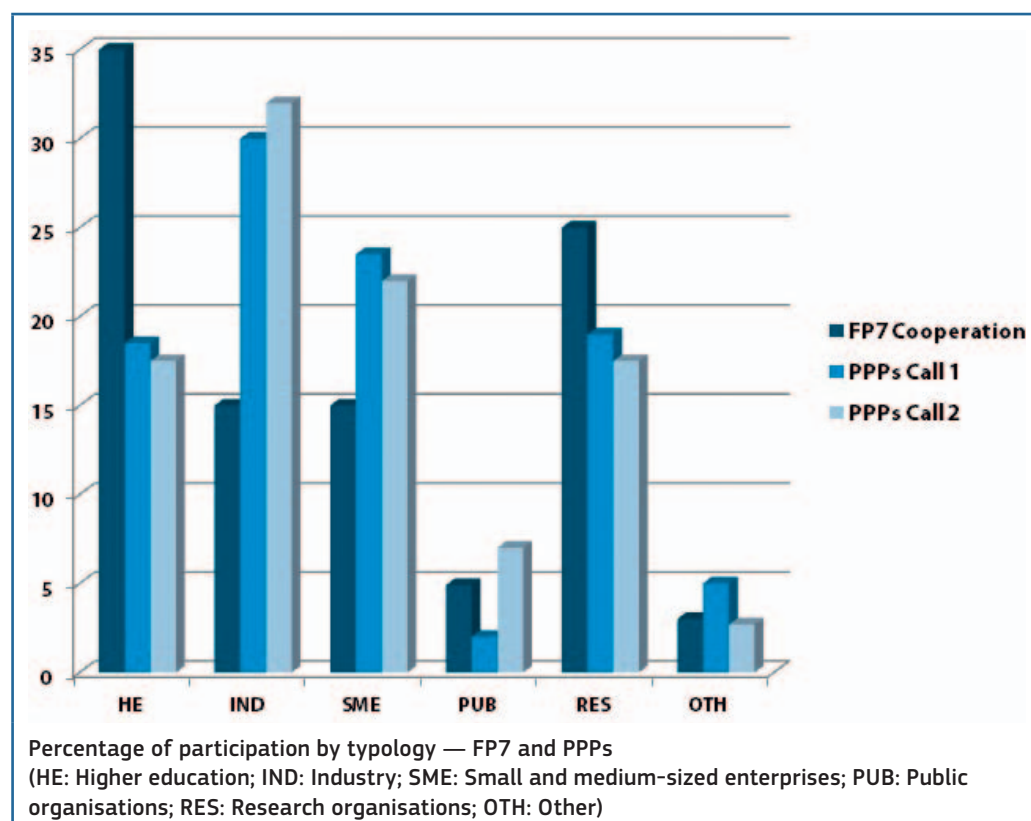
Following a European-wide, open and transparent stakeholder consultation process, the coordinated strategy between the public and private partners resulted in the Factories of the Future PPP strategic multi-annual roadmap 2010–13'. Manufuture ETP, EFFRA, seven Manufuture sub-platforms, the network of 26 Manufuture NRTPs, and 11 other manufacturing-related ETPs were involved in the process.

On the basis of this roadmap, the Factories of the Future PPP has launched four calls for proposals within FP7. The overall achievements include:

- increased public and private investment;
- increased participation of industry (including SMEs);
- streamlined procedures and increased efficiency;
- the promotion of cross-disciplinary and trans-European research.

In the first call, the Factories of the Future PPP achieved a proposals success rate of 26 % (7–11 % in the NMP 2009 call, depending on the instrument) and an average ‘time to grant’ of 8.5 months (in comparison to the average 12 months in FP7). The launched projects have brought together 216 stakeholder organisations, which are working across borders on the basis of a total R & D investment of EUR 141 million³².

Industry receives around 54 % of the funding allocated to the selected projects (an average of 29 % in FP7 2009 Calls), with SMEs representing 32 % of the funds (11.7 % in the FP7 Cooperation Programme)^{33, 34}.



Today, 98 projects that successfully passed through the first three Factories of the Future PPP calls are already running. As shown above, participation of industry and SMEs is well above the average of FP7 projects.

³² Interim assessment of the research PPPs in the European Economic Recovery Plan, European Commission, 2011.

³³ Interim evaluation of the seventh framework programme, Report of the Expert Group, European Commission 2010.

³⁴ Third FP7 Monitoring Report, European Commission 2010.

These projects are now starting to deliver as can be seen in the following examples:

- **The PLANTCockpit project:** *Production Logistics and Sustainability Cockpit.*

The 'Production Logistics and Sustainability Cockpit' (PLANTCockpit) research project aims to incorporate existing enterprise resource planning systems, as well as MES (manufacturing execution systems), SCADA (supervisory control and data acquisition) and special-purpose solutions. It provides the integration of visibility and process needed to be able to actually identify potential and optimise intralogistics processes with respect to yield, quality, energy consumption and other such indicators.

The project team's vision is to offer PLANTCockpit to manufacturing communities as the central environment for monitoring and controlling all intra-logistical processes. The research project aims to supply production supervisors, foremen and line managers with the required visibility to make well-informed decisions for optimising plant processes.

The PLANTCockpit prototypes are currently being demonstrated in five use cases, that are being documented in terms of industrial context, focus area of the use case and business benefits.

- **The TAPAS project:** *Robotics-enabled logistics and assistive services for the transformable factory of the future.*

TAPAS will make it possible for future factories to engage in more effective and streamlined production, regardless of changes in volumes and product type.

To do this, TAPAS is focusing on the following tasks: Development of mobile robots with arms to make logistical tasks more flexible and automation of assistive tasks which naturally build on logistical tasks, e.g. pre-assembly or machine tending with inherent quality control, since the simple movement of parts around the shop floor does not generate value in itself.

Through this additional creation of value and faster adaptation to changes, with tasks being completed in a shorter time, TAPAS will yield much earlier returns on investment and as such deliver better results. The project consortium is testing and validating the above developments with two pilot installations of increasing complexity and scale.

- **The COMET project:** *Plug-and-produce components and methods for adaptive control of industrial robots enabling cost-effective, high-precision manufacturing in factories of the future.*

The COMET project aims to overcome the challenges facing European manufacturing industries by developing innovative machining systems that are flexible, reliable and predictable with an average of 30 % cost efficiency savings.

Since its start in 2010, the COMET project has established seven robot cells across Europe. Machining experiments performed in these cells have produced valuable data for machining with robots and the issues that may occur. The project will continue to integrate each part of the COMET platform and concentrate on demonstrating the advantages of robot machining in a variety of applications such as automotive parts, mould and die components and aerospace parts.

- **The Phocam project:** *Photopolymer-based customised additive manufacturing technologies.*

Phocam is developing innovative lithography-based additive manufacturing systems which will facilitate the processing of photopolymer-based materials in the new factory environment. The project brings together industrial expertise and knowledge in the fields of supply chain and quality management, software development, photopolymers and ceramics, high-performance light sources, as well as systems integration so as to provide a fully integrated process chain.

The consortium relies on two main techniques to process radiation-curable materials:

- digital light processing (DLP) for processing ceramic-filled photopolymers, which will lead to the production of fully dense ceramic parts at the end of the process chain;
- two photon polymerisation (2PP), which will be used to create high-resolution structures which have features in the range of 100–200 nm.

Both processes are fine-tuned to reduce system costs, while significantly increasing throughput and reliability. The ultimate goal is to deliver ‘first-time-right’ strategies for end users. This requires the development of supply chains with integrated sensors to detect quality. The project targets applications in various industries, e.g. on thread guides on textile machinery, ceramic moulds for the manufacture of high-performance turbine blades and microstructures for computer tomography equipment.

- **The FoFdration project:** *The Foundation for the Smart Factory of the Future.*

FoFdration establishes a universal manufacturing information system based on a ‘data integration’ standard such as STEP and its EXPRESS language, which allows individual entities and their associated devices to share data in a common format. This foundation will then allow the smart factory architecture to be implemented based on a high bandwidth ‘manufacturing information pipeline’ for data interoperability.

Developments of the FoFdration project are being demonstrated through four demonstrators, three of them coming from the aeronautic and automotive industry while the fourth is to demonstrate the concept of ‘ubiquitous factory’ based on plant-wide integration and optimisation across the whole enterprise workflow.

Results and innovations will be communicated and shared with the European manufacturing industry and educational institutes through demonstrations, extensive dissemination activities, and Living Labs.

All Factories of the Future projects are promoted by the annual EFFRA project brochures and the EFFRA projects web portal (see also section 13.5.1).

A fruitful and efficient collaboration with the EU institutions has been fundamental to the success of this joint initiative so far. The support of the President of the European Commission, José Manuel Barroso, who introduced the idea of the Factories of the Future PPP, has greatly contributed to this success.

Multi-level interactions have taken place between the Manufuture/EFFRA communities and the European Commission, in particular with DG Research and Innovation and DG INFSO. Some major milestones have been achieved in the context of this process, such as the meeting with the



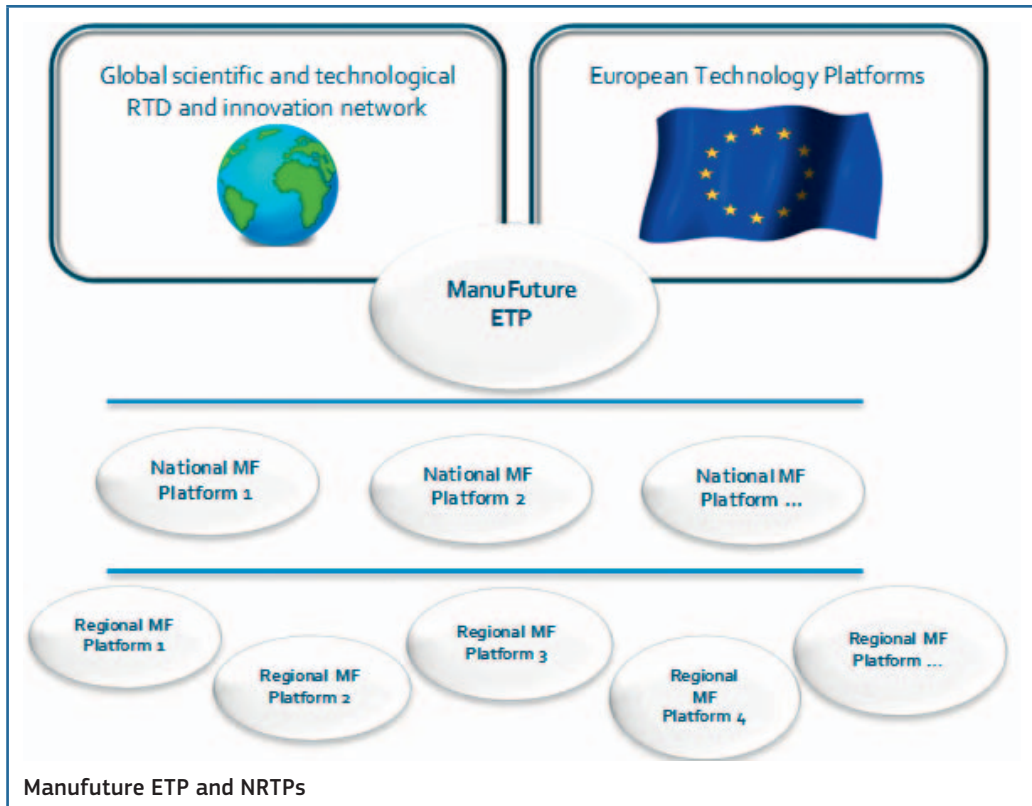
EFFRA projects brochures — examples of industrial commitment

President of the European Commission, José Manuel Barroso, in July 2008, the meetings with Commissioners Janez Potočnik and Viviane Reding in July 2009, the meeting with Commissioner Geoghegan-Quinn in July 2011 and the discussions with Vice-President of the European Commission Neelie Kroes during the Factories of the Future ICT Conference organised in 'CEBIT 2012'.

Interactions have also taken place at a political level, through a series of events in the European Parliament. Besides smaller meetings with key persons, such as MEP Maria Da Graça Carvalho, Manufuture/EFFRA communities have been involved in a number of bigger roundtable debates (e.g. April 2010, January 2011, May 2011, January 2012), which have attracted many MEPs.

Taking into consideration the PPPs' developments so far, the 'PPPs' Sherpa Group' recommended that the EC should continue to strengthen its cooperation with the legal entities representing the private sector within the research PPPs under the 'European Economic Recovery Plan'. EU ministers have also recognised the progress of these initiatives and given continued support to them in the Competitiveness Council meetings.

Complementary to the work done at the level of European Research Programmes, the Manufuture ETP has been active also at national and regional levels, promoting a better coverage of the entire innovation cycle, a more effective and efficient alignment between European and national/regional policies, programmes and initiatives and also a higher involvement and participation of manufacturing companies, specially SMEs.



At transnational/regional level, these activities have included the creation of a Eureka initiative (Manufuture Industry Cluster) and a close cooperation with existing initiatives, like Eureka PRO-FACTORY and Manunet (ERA-NET), aiming, for example, at joint roadmapping activities. At national/regional level, Manufuture ETP has inspired, supported or created many initiatives, namely clusters and complementary funding programmes, using national/regional funds (including structural funds) to support other research topics and/or innovation-related activities.

This complementary work developed by the Manufuture ETP during the last 5 years in themes like joint roadmapping, alignment between European and national/regional policies, funding programmes and the coverage of the entire innovation cycle, has gathered a significant and important set of information and experiences, capable of paving the way for a better and faster implementation of the Horizon 2020 programme in the manufacturing area.

4.2 The future

The success of the Factories of the Future PPP requires a critical mass of stakeholders, leadership and clear industrial commitment, in particular:

- The implementation of this roadmap goes beyond the capacity of individual Member States. A critical mass of stakeholders and a pan-European approach is required.
- Implementation requires a substantial, long-term commitment and the leadership of industrial companies and associations both at executive and working levels.

Commitment is particularly important for generating impact. There EFFRA commits to the proactive stimulation of technology transfer and market uptake:

- by dissemination of project results;
- by driving the continuation of the innovation process after the projects finish;
- by linking projects through the unique FoF projects database;
- by clustering projects;
- by organising workshops that match projects with loans providers (see also section 0).

The private side will foster the exploitation of the results in Europe to enhance the impact by:

- pursuing a leverage factor of investments for industrial deployment, that is expected in the range of 5 (manufacturing technologies, e.g. machining) to 10 (new technologies, e.g. 3D printing);
- inviting open innovation around demo-activities (strengthen start-ups and SMEs);
- giving priority to technology development in Europe; look for opportunities for delocalised production within Europe (e.g. linked to EU regional activities — smart specialisation);
- facilitating that successful results go into standard best-practice (for fast market uptake);
- disseminating successful results within and between sectors and across value chains through effective linking of participants (database, clusters, workshops, best-practice, etc.);
- promoting the use of the project results to develop product-enhancing services;
- developing activities for training the trainers and the workforce, and to attract young people;
- promoting new business models and market development along the value chains;
- encouraging cross-sectoral cooperation in manufacturing;
- working with other PPPs for proper alignment of goals and activities to ensure synergies;
- supporting companies in pursuing new ways to exploit R & D results and new products.

The industrial commitment for the Factories of the Future PPP, now and in the future, is furthermore exemplified by:

- The successful implementation of the Factories of the Future PPP programme under FP7 as a result of the successful synergy between the private and public partners.
- The big increase of industry involvement (including SMEs) in the Factories of the Future PPP research projects in comparison with the FPs.
- The associated matching of funds in-kind to complement the EC support to the projects.

- Proactive engagement in various meetings between EFFRA representatives and EC services at all levels — commissioners, directors-general, directors, heads of unit of both DG Research and Innovation and DG Connect.
- The active industrial involvement on all Factories of the Future-relevant activities (strategy, evaluation panels, etc.) and bodies (Manufuture, EFFRA, FoF AIAG, etc.). The proactive industrial work on developing the Factories of the Future roadmap, as well as its continuous fine-tuning and formal updating every 2 years.
- The financial commitments of all stakeholders involved to bear costs associated with the roadmapping work which includes the organisation of dozens of workshops, seminars, assemblies and conferences.
- The PPP Declaration of Commitment (see extract below), signed in Aarhus by the Chairman of EFFRA, together with other representatives of industrial sectors. The declaration was handed over to the Danish Minister of Science, Technology and Innovation (representing the Danish EU Presidency) and to the Director for Industrial Technologies at the European Commission, Mr Herbert von Bose. It expresses the need for action and commitment from all partners, public and private, to ensure that the European manufacturing industries stay competitive and continue to create economic and social wealth in Europe.
- The annual publication by EFFRA on the Factories of the Future projects (including both summaries from newly launched projects and progress report from existing projects).

Industrial commitment

Industry's role is to participate as a partner in this collaborative research and innovation and to ensure that successful joint demonstrations are followed by commercial investment in Europe into new products and processes, which will also trigger job creation.

With this requirement well recognised, our industries are ready to enter into joint programmes and investments to develop, implement and deploy innovative solutions that will secure the sustainability and competitiveness of European industry along with the highly skilled jobs that it provides.

Investing our finances, resources, knowledge and skills will represent our strong and determined commitment to this undertaking, and we foresee that our own investment in Europe will provide an important leverage to that of the public sector and have an impact on growth, competitiveness and jobs.



PPP Declaration of Commitment and signatures of representatives (Aarhus, July 2012)

An expanding, strong and motivated industrial, research and academic community is fully engaged in the Factories of the Future PPP. This and the above described experiences will ensure a long-term commitment to the partnership.



Discussing innovation strategies and showing industrial commitment to 'factories of the future'.

(Top)

PPP Info days 2011: Mrs Máire Geoghegan-Quinn, Commissioner for Research, Innovation and Science., Prof. Dr Heinrich Flegel, (Daimler AG) Chairman of the Manufuture HLG and Dr Massimo Mattucci (COMAU), Chairman of EFFRA.

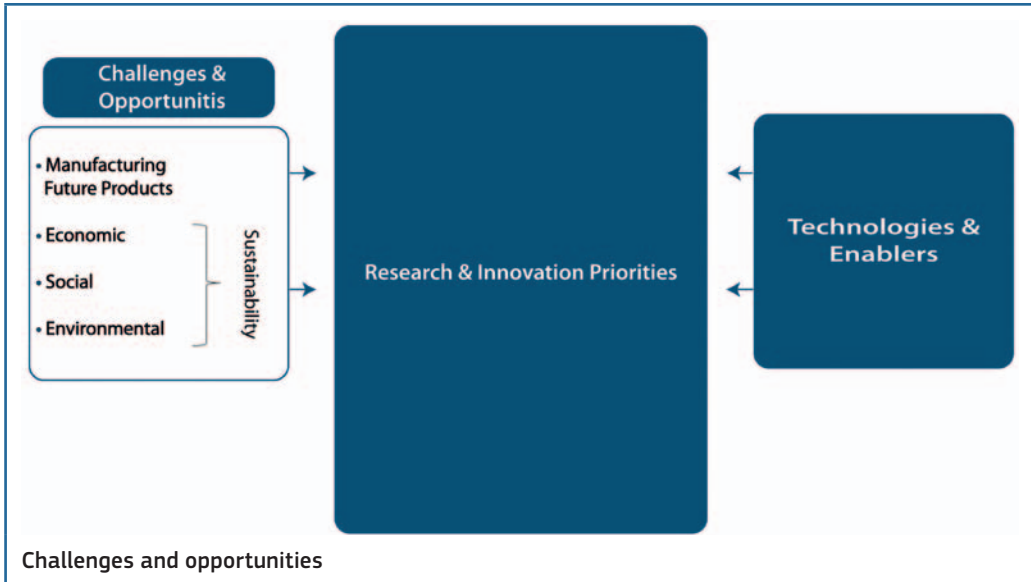
(Bottom)

CeBIT 2012: 'Executive Roundtable': Mrs Neelie Kroes, VP European Commission, 'The Digital Agenda', Mr Jason Yotopoulos, (Executive VP, Head of Global Research and Business Incubation at SAP AG), Mr Philippe Forestier (Executive VP Global Affairs and Communities at Dassault Systèmes), Dr Peter Post (Head of Research and Programme Strategy, Festo AG and Chairman Manufuture Germany) and Dr Massimo Mattucci (COMAU and Chairman of EFFRA).

Part II: Research and innovation strategy

5 Manufacturing challenges and opportunities

In what follows, the manufacturing challenges and opportunities are described, including pointers to technologies and enablers. These manufacturing challenges and opportunities determine the desired impact of the research and innovation priorities that are developed in this roadmap. An integrated approach in addressing the challenges is of crucial importance.



5.1 Manufacturing the products of the future

The grand societal challenges generate the need for a wide range of products that should be manufactured at an affordable price. Manufacturing is therefore a key enabler technology to realise these products and solutions.

Examples of this include:

Sustainable mobility requires the availability and cost-effective integration of new and affordable propulsion systems including hybrid/electrical solutions, and specifically new battery technologies. Correspondingly, factories of the future will feature increasing flexibility with multi-propulsion production lines, maximising the exploitation of plant capacity, implementing a high level of workplace ergonomics and safety, while using advanced materials, power micro-electronics, etc.

Improved recycling (re-manufacturing) solutions that address scarcity through the reuse of valuable materials in a cost-effective way, requires completely new types of factories. The scarcity of raw materials will mean that products of the future will have to be recycled to retrieve valuable materials.

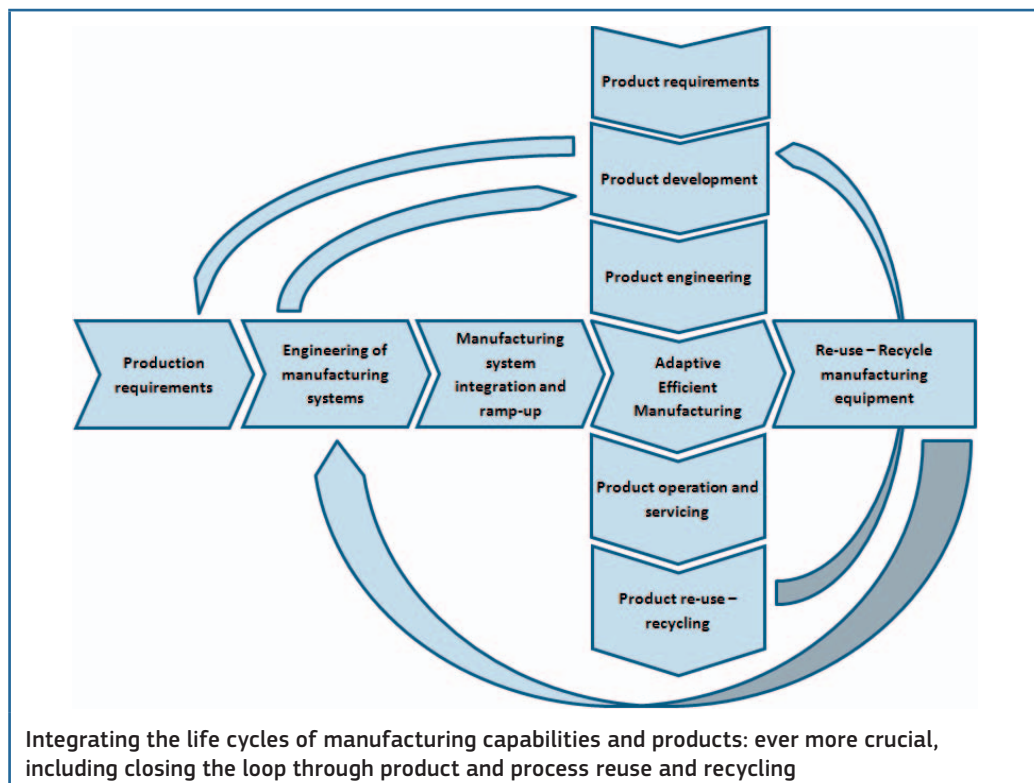
Better home care for the elderly requires smarter electronic products which require the consumption of fewer materials and energy resources during their production. Key parts will become substantially smaller, while increasing automation is introduced by competing regions (e.g. Asia). Time, cost and quality require that these products be manufactured in Europe, close to the consumer and in urban environments. Furthermore, better medical care will include highly individualised pharmaceuticals produced, on demand, through advanced manufacturing in urban pharmaceutical factories.

Sustainable energy through solar, wind and tidal power solutions and energy storage, requires advanced and competitive manufacturing capabilities. This will enable Europe to generate more sustainable energy and increase its energy independence.

The Factories of the Future roadmap connects the grand societal challenges with the manufacturing capabilities required within Europe to address them. In this context, key enabling technologies (KETs), including photonics, micro and nano-electronics, industrial biotechnology, and nano-materials, will be required to support the introduction of future products in the years ahead.

The driving forces for new products are at the same time global (consumer electronics, connectivity, telecommunications, mobility, big data intelligence, solid state lighting ...) and local, where local regulations and local market needs will push for products with specific requirements in a specific geographic area. In the European market, new specific requirements are arising due to environmental focus (e.g. green labelling, reduction of material waste), due to the new needs of the ageing society and due to the customisation and personalisation of goods.

Global competition requires the launch of new products with a shortened commercial life cycle and with a high degree of personalisation for adapting to individuals biometric parameters or for satisfying unique users' preferences. On the other side, sustainability is pushing for an extension of the life cycle itself. This dilemma can be solved by highly personalised products through software functionalities, which can easily sustain high frequency of renewal, or by the design of products, processes and systems that allow the sustainable re-manufacturing and materials recycling.



Most of the industrial sectors which are crucial to maintaining manufacturing and jobs in Europe face the need to innovate products through the use of new materials and/or new functionalities, requiring manufacturing approaches that fully exploit the improved functionality and versatility of design.

Service provisioning and enhanced functionalities in future products will also require the introduction of increased product intelligence, such as the increased use of embedded mechatronics in components, which will require the design and production methodologies to evolve as a consequence.

Last but not least, the future factories themselves are to be considered as future products, including the consideration of user (worker)-experience in their design.

5.2 Economic sustainability of manufacturing

In the pursuit of long-term strategic competitiveness, Europe must lead in the creation of value through the design and production of the products of the future which satisfy not only the ever-changing needs of society, but also offer the potential of opening/creating new markets in Europe and abroad. High value added manufacturing should be a distinctive factor for European industry, producing an increasing number of high-tech and smart products, including KET³⁵-enabled products.

Any kind of sustainability and societal impact can only be achieved if manufacturing is competitive and is able to generate the income required to pay knowledge-workers and to invest in environmentally friendly and worker-friendly factories. Hence, economical sustainability is vital to realising any sustainability. Economic sustainability through high value-added manufacturing using production processes with a high degree of intelligence should be a distinctive factor for European industry.

Economic sustainability relies on an optimal implementation of the whole range of technologies and enablers, in particular involving ICT and robotics-mechatronics technologies, including embedded sensors connected to controllers, ERP, MES and predictive maintenance systems, enabling online, real-time and full production quality control. Europe requires leadership in the development, adaptation and commercialisation and speeding up of these innovation processes.

5.2.1 Addressing economic performance across the supply chain

Over the next decade, for a wide range of complex products, the holistic optimisation of performance will push towards new multi-material and multi-functional solutions. This will result in a change in the manufacturing paradigm by introducing new methods and process technologies within the factory in order to ensure both the required quality and sufficiently high productivity to guarantee cost-efficient manufacturing. Economic sustainability will require a redesign of products and production processes respecting the manufacturing conditions and strengths of Europe. In turn this will imply maximising manufacturing efficiency by implementing, where

³⁵ Key enabling technologies.

adequate, automated, complex and precise manufacturing steps, which can be supported by advanced technologies and knowledge available in Europe.

From the perspective of mass production, economic viability is also of fundamental importance. Solutions like the adoption of lighter and higher resistant materials such as titanium and carbon composite remain critical from a cost perspective, while material availability and new regulations concerning end of life (EoL) already constitute significant challenges for industry.

To achieve solutions which are truly viable, the ratio of cost to performance must be reduced to improve global competitiveness. The assessment of manufacturing related cost and investment factors will be strategic for the selection and optimisation of innovative product/process/system solutions. New appropriate cost-modelling techniques are needed to evaluate the future cost of products manufactured either by existing or new technologies, considering future scenarios where market needs, production volumes and technology maturation cause the continuous evolution of product/process/system solutions.

These challenges must be faced along the entire supply chain involving OEMs, component suppliers and SMEs due to the typical supply chain of a complex product.

5.2.2 Realising reconfigurable, adaptive and evolving factories capable of small-scale production

Realising reconfigurable, adaptive and evolving factories capable of small-scale production in an economically viable way is needed to face better and promptly the uncertain evolution of the market or the effect of disruptive events. Manufacturing enterprises are pushed to take 'glocal' actions, i.e. thinking globally but acting and staying economically compatible with the local context.

This involves managing the transition towards new generations of products (see section 5.1), allowing a stage of contemporary production of new and old products scaling up investments only when the market is proven (e.g. product with new functionalities by means of smart and reliable integration into conventional or new sub-components and materials). Upgradable, evolvable machine, cell and plants are necessary for flexible and responsive manufacturing. New organisational approaches and tools are required for manufacturing a mix of different products within the same cell/line/plan, optimising the internal and external logistics (including the supply chain) which often becomes the real obstacle when very flexible production capability is available. Highly flexible manufacturing processes, tools and systems will enable the manufacturing of smaller and more personalised batches. Novel industrial processes with an increased level of customisation, tailored for individual needs, involving the user/customer in the loop at the early step of design.

5.2.3 High-performance production, combining flexibility, productivity, precision and zero-defect while remaining energy- and resource-efficient

High-precision manufacturing and micro-manufacturing of complex products obliges precision manufacturing to increase the accuracy of machines and controls. This requires the introduction of new material-processing technologies (including cleaning methods) and novel measurement technologies.

High-performance production requires an increase in terms of speed, quality and reliability of existing manufacturing technologies. It requires process monitoring and modelling or simulation approaches, associated with novel optimisation and maintenance strategies. Innovative manufacturing technologies should also be developed; increasing the value-creation of one single operation. High-performance production will be furthermore largely supported by introducing advanced mechatronics and embedding intelligence in manufacturing equipment.

High-performance production also involves the management and processing of ever growing volumes of data and information from the factory floor up to the supply chain level, reaching out to workers and customers.

5.2.4 Resource efficiency in manufacturing — including addressing the end-of-life of products

Using less resources and reusing or recycling products or components of products generates economic savings and reduces the environmental impact of manufacturing (This manufacturing challenge is addressed more in detail under section 5.4).

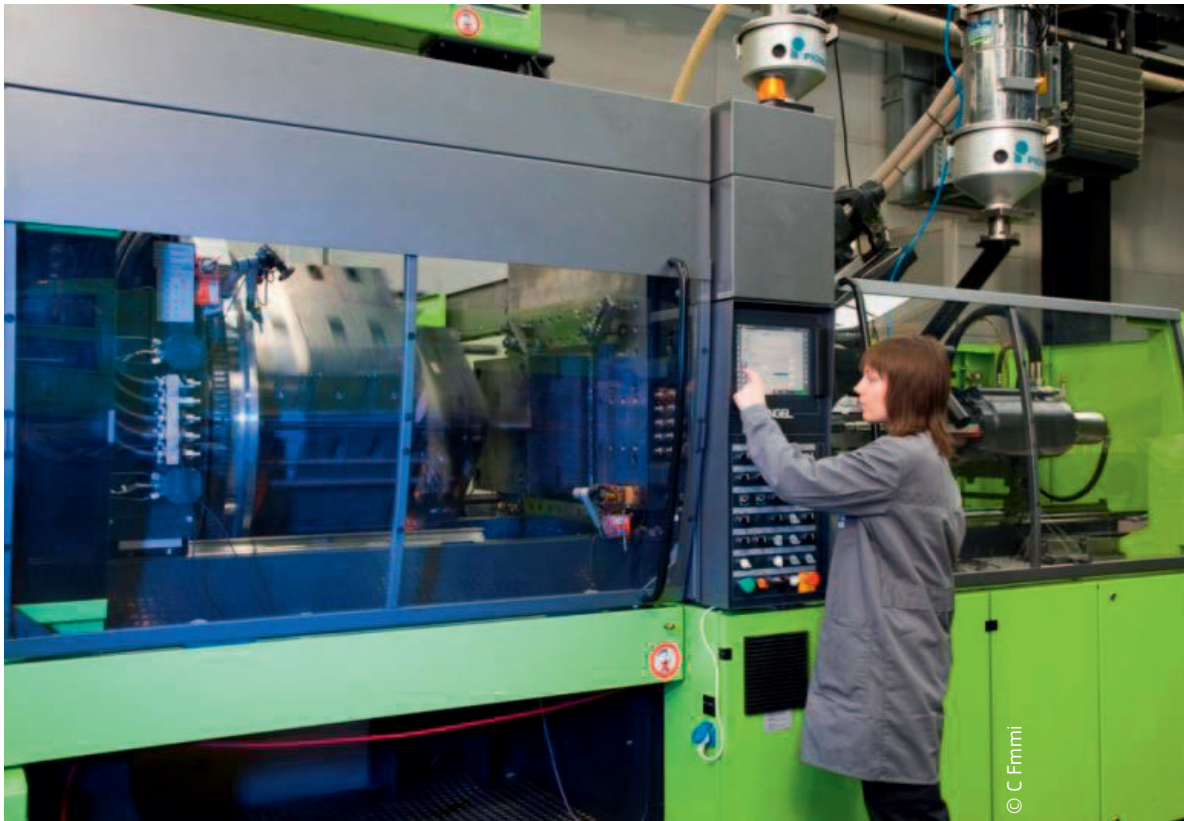
5.3 Social sustainability of manufacturing

The Europe 2020 strategy emphasises the need for organising and designing manufacturing in a way which ensures that manufacturing enterprises will remain socially sustainable while still achieving global competitiveness. To resolve these issues, interdisciplinary research and innovation is needed to provide the basis for the design of adequate manufacturing environments and workplaces. As a result, human capability and machine intelligence will be integrated within production systems that can achieve maximum efficiency as well as worker satisfaction. Research efforts should tackle social sustainability challenges at all levels of manufacturing industries. This effort will be economically very successful, while still improving corporate social responsibility, inclusive workplace design, and efficient use of ICT to leverage the competence of the European workforce.

5.3.1 Increase human achievements in future European manufacturing systems

The balance between cost-efficient automation and intelligent use of human capacities in manufacturing will determine the choice for future production and factory location. Efforts are needed to design factory processes for locations that used to be high-labour costs regions, e.g. Europe. To achieve competitive and sustainable manufacturing here, performance must be radically increased by smart and semi-automated manufacturing systems. Future knowledge-workers should interact dynamically and share tasks with smart manufacturing technology. Collaboration and allocation of tasks between humans and manufacturing technology should be done through appropriate and adjustable levels of physical and cognitive automation. Human capabilities should be enhanced e.g. by safe human-robot collaboration, mobile and location-aware communication devices, and customer-worker collaboration capability. Within this context, manufacturing education has a key role in preparing humans for new approaches to knowledge communication, skill and competence development, and advanced training.

Enhanced competence and capability of knowledge-workers will increase manufacturing flexibility and quality, while reducing complexity and process time, simultaneously enhancing



economic sustainability. Interdisciplinary research and innovation activities will provide value systems that inspire humans to achieve results not thought to be possible today. Future enabling methods include virtual and analytical task analyses, dynamic risk and safety assessment, cognitive workload analyses, and competence management tools.

5.3.2 Creating sustainable, safe and attractive workplaces for Europe 2020

The Europe 2020 strategy highlights future demographic challenges. It is therefore vital that manufacturing workplaces are inclusive, thereby adapting work demands to the physical and cognitive capabilities of workers, especially for older workers and disabled people. Innovative and supporting technologies for these challenges need to be worked out by research. The next generation workforce is being raised in an Internet society and is accustomed to a vast range of technical gadgets and rich interaction techniques. The workers of 2020 need to be motivated to even consider going into manufacturing employment, but they will be able to stand out as the knowledge-workers as identified in the above paragraph. This will challenge present value systems of leading manufacturing industries and research will bring manufacturing to new forms of collaboration and business models.

Methods to achieve sustainable and attractive work will change state-of-the-art approaches, e.g. knowledge-management technology, training environments, risk and safety analyses, production ergonomics, and work organisation models. Future enabling methods will push the boundaries of simulated work environments, augmented reality, and virtual human models in order to visualise and analyse the behaviour of broad ranges of workers.

5.3.3 Creating sustainable care and responsibility for employees and citizens in global supply chains

Sustainable consideration of employees is reflected in company reputation and customer respect. European enterprises will operate in global supply chains, therefore age and employment systems must adapt to local contexts and cultures. Companies must also sustain control, safety, and well-being to attract new employees and customers.

In the near future, enterprises will have to seek production sites in places of high population density. Accelerated population aggregation in urban regions will affect citizens living close to manufacturing plants. Consideration of social responsibility to local environments is increasingly important and needs scientific answers as to how to make manufacturing plant location economically profitable with respect to energy demands, quality of living, natural resources, and safety. Future enabling methods will include new organisational models, new value systems, and new global business models. Sustainable care and responsibility is closely linked to environmental and economic sustainability. This will attract highly motivated and skilled employees.

5.4 Environmental sustainability of manufacturing

Phenomena such as climate change, the depletion of and uncertainty of access to raw materials and resources, growing populations, pollution and consumption levels will push changes in European manufacturing. Such changes include manufacturing that is less dependent on energy and uses materials more efficiently while generating less emissions and waste, making the transition from fossil to bio-based resources.

Manufacturing today addresses a constantly increasing demand for consumer goods since living standards are on the rise. As a consequence of this trend, the consumption of raw materials and energy by the manufacturing industry keeps increasing. In 2005 the energy consumption of the manufacturing industry was 297 Mtoe (million tonnes oil equivalent), which accounted for 27.9 % of the total energy consumption in Europe^{36, 37}. Moreover, manufacturing is one of the primary sources of hazardous emissions and waste generation. In 2006, manufacturing industries accounted for 25.9 % of GHG emissions, 15.5 % of acidifying substances and 27.0 % of ground ozone precursors. In 2008, more than half (54.6 %) of the waste generated in the EU-27 by businesses could be attributed to industrial activities (manufacturing, mining and quarrying)³⁸.

5.4.1 Reducing the consumption of energy, while increasing the usage of renewable energy

Reducing the consumption of energy, while increasing the usage of renewable energy, is crucial as nearly one third of global energy demand and CO₂ emissions are attributable to manufacturing³⁹. This requires considering energy efficiency from a more systematic point of view in the design phase of manufacturing equipment. This also requires consideration of the

³⁶ European Commission, 2020 vision: Saving our energy, 2007.

³⁷ Energy and Environment Report 2008, European Environment Agency.

³⁸ Eurostat Yearbook 2011.

³⁹ ICT and energy efficiency, the case for manufacturing.

factory-level and the exploitation of innovative energy-efficient actuators and components to their full extent while also considering the entire supply chain, from raw material manufacturing stages up to the final component manufacturing process.

Process monitoring and control can provide support here, for optimising the performance and resource consumption on machine level and factory and supply chain level, where decision-support systems consider energy consumption globally. This includes selectively switching off systems and components, using smart sensor networks and energy-efficient scheduling approaches, reducing peaks in energy demand, recovering and reusing electrical energy from decelerating drives or process heat, etc. Process monitoring should also support the consideration of resource-efficiency in maintenance approaches.

5.4.2 Reducing the consumption of water and other process resources

Reduction of resource consumption should not be limited to energy but also include water and any other material resource that does not end up in the final product, but instead ends up in the form of waste or low value-added by-product

5.4.3 Near-to-zero emissions, including noise and vibrations, in manufacturing processes

Simulation and modelling methods and tools that consider resource consumption and emissions will have an impact both in the design and operational phase of manufacturing systems. Here, it is important to use life cycle analysis in order to avoid sub-optimisation and to promote transparency.

5.4.4 Optimising the exploitation of materials in manufacturing processes

As a limited amount of material resources is available for producing a growing amount of goods for growing emerging markets, these resources are becoming more relevant to the product's final economic and environmental cost. Increasing the capability of manufacturing to process advanced or environment-neutral materials that ease materials recycling, reuse and re-manufacturing are critical factors for sustainable competitiveness.

Other approaches are reducing the consumption and the substitution of raw and strategic materials by using new (non-fossil based) materials, e.g. biomaterials, for which new manufacturing technologies need to be developed or conventional manufacturing processes need to be adapted.

Optimal use of materials also involves increasing the deployment of near-net manufacturing processes, such as additive manufacturing, hereby reducing raw material consumption and allowing production of highly customised level design.

The use of waste as a resource (such as heat, energy and raw material) within the manufacturing process is to be considered here as well. Another aspect is the need for optimising the exploitation of manufacturing equipment at the end of life.

5.4.5 Co-evolution of products–processes–production systems or ‘industrial symbiosis’ with minimum need of new resources

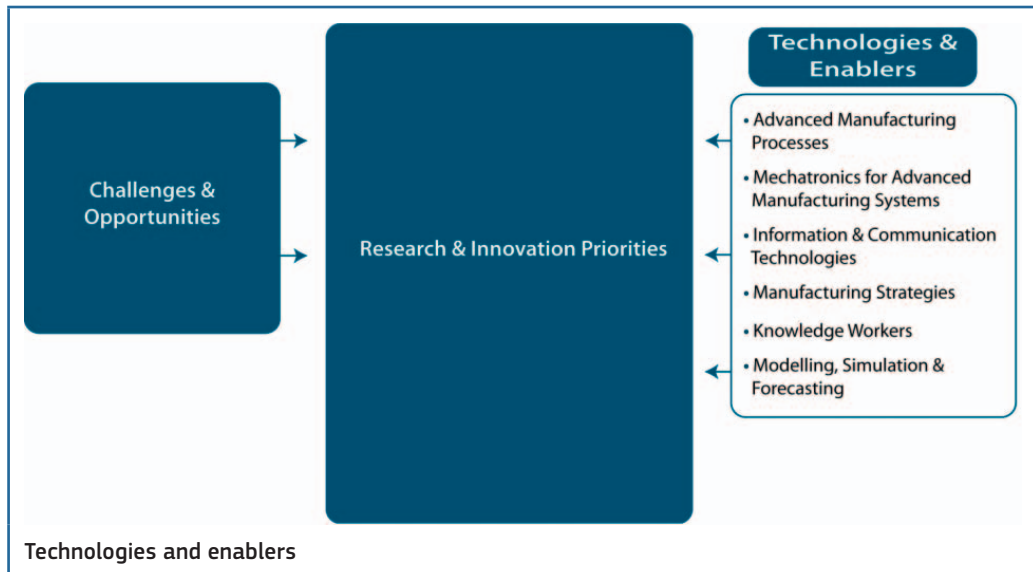
Co-evolution of products–processes–production systems involves engaging traditionally separate industries involving physical exchanges of materials, energy, water, and/or by-products⁴⁰ and requires an optimised interaction of manufacturing with transport and critical infrastructures. This may include engaging raw material suppliers and final transformation industries in developing new innovative combined processes which result in the elimination of overlapped manufacturing stages.

Note: Environmental sustainability is a driver for new products/markets. Manufacturing technologies are a prerequisite for realising these resource-efficient next-generation products (see section 5.1).

⁴⁰ *Encyclopaedia of Energy*, Cleveland C. J, Oxford.

6 Key technologies and enablers

The key technologies and enablers of the factories of the future, including KETs, are described below. The research priorities of the Factories of the Future PPP will focus on the development, application or integration of a set of enablers and technologies in order to generate impact in terms of the previously identified challenges and opportunities.



6.1 Advanced manufacturing processes

The efficiency and sustainability of both the manufacturing of actual and future products is still very much determined by the processes that shape and assemble the components of these products.

Innovative products and advanced materials (including nano-materials) are emerging but are not yet developing to their full advantage since robust manufacturing methods to deliver these products and materials are not developed for large scale. Research is needed to ensure that novel manufacturing processes can efficiently exploit the potential of novel products for a wide range of applications.

Advanced manufacturing processes that require focus are:

- additive manufacturing;
- photonics-based materials processing technologies;
- shaping technology such as (incremental) forming and machining, to address challenges related to 'difficult-to-shape' materials and to explore new processing methods to achieve micro-nano-sized microstructure components;

- high productivity and ‘self-assembly’ technologies development of conventional (joining, forming, machining) and new micro/nano-manufacturing processes;
- methods for handling of parts, metrology and inspection, including non-destructive examination technologies ensuring the ability to manufacture at scale (volume) with high reliability and in less controlled environments such as regular workshops;
- flexible sheet-to-sheet (S2S) and roll-to-roll (R2R), building in plastics electronics, large volume patterning at nano-scale (photolithography) and new materials and greater use of space on CMOS;
- innovative physical, chemical and physicochemical processes;
- replication, equipment for flexible scalable production/assembly and coatings;
- integration of non-conventional technologies (e.g. laser and other jet technologies, ultrasonic or low frequency processes) towards the development of new multifunctional or hybrid manufacturing processes (including in process concept: inspection, thermal treatment, stress relieving, machining, joining, metrology, inspection, thermal treatment, stress relieving, etc.

6.2 Mechatronics for advanced manufacturing systems

Manufacturing systems include machines, modules and components that integrate mechanics, materials processing technologies, electronics, and computing capabilities (ICT technologies) to perform desired tasks according to expectations. Mechatronic systems do not only interface with materials, parts and products, they also cooperate safely with factory workers and communicate with other systems in the factory. Also they connect to manufacturing execution and monitoring systems on a higher factory and management level.

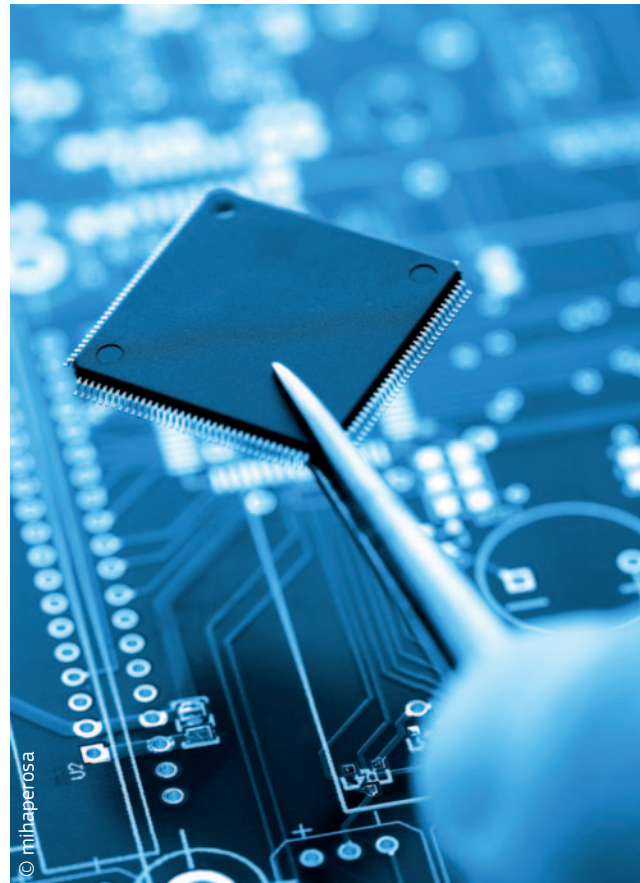
Hence manufacturing systems are becoming smarter in order to generate high value (quality, productivity) while consuming less energy and generating less waste. They feature high levels of autonomy and cognitive capabilities, largely inspired by and making use of robotic technologies.

The needs for reconfigurability and the ability to produce smaller lot sizes of personalised products require not only smart mechatronics but also higher efficiency and effectiveness in the planning and engineering of such manufacturing systems.

A major impact is expected from the following technological areas:

- **Control technologies** will further exploit increasing computational power, sensing capabilities and intelligence in order to come forward to the demands of increased speed and precision in manufacturing. Advanced control strategies will allow the use of lighter actuators and structural elements to obtain very rigid and accurate solutions, replacing slower and more energy-intensive approaches. Learning controllers adapt the behaviour of systems to changing environments or system degradation, taking into account constraints and considering alternatives, hereby relying on robust industrial real-time communication technologies, system modelling approaches and distributed intelligence architectures.

- **Cognition-based intelligent features within machinery and robots** will radically change their interfacing towards human operators in manufacturing environments. Machinery and robots will follow an intuitive cooperation and will use navigation and perception technologies to be aware of its work and of its environment.
- **Advanced machine interaction with humans through ubiquity of mobile devices** and novel natural interaction devices will enable users to receive relevant production and enterprise-specific information regardless of their geographical location and tailored to the context and the skills/responsibilities they own. Interactions with ICT infrastructures and equipment will be intuitive and natural language-like.
- **Continuous monitoring** of the condition and performance of the manufacturing system at process, component and machine level, enables sustainable and competitive manufacturing, also by introducing autonomous diagnosis capabilities and context-awareness. Detecting, measuring and monitoring the variables, events and situations will increase the performance and reliability of manufacturing systems. This involves advanced metrology, calibration and sensing, signal processing and model-based virtual sensing for a wide range of applications, e.g. event pattern detection, diagnostics, anomaly detection, prognostics and predictive maintenance.
- **Intelligent machinery components and architectures** will enable the deployment of safe, energy-efficient, accurate and flexible or reconfigurable production systems. This includes the introduction of smart actuators and the use of advanced end-effectors composed of passive and active materials for complex part manipulation or assembly. These technologies enable noise and vibration reduction: not only to increase speed, precision and quality but also from environmental and social point of view. Smart components enable higher levels of modularity and increased performance and scalability in dynamic situations.
- **Energy technologies** are gaining importance, such as (super)capacitors, pneumatic storage devices, batteries and energy-harvesting technologies.
- Production equipment does not yet take full advantage of the benefits that **new and advanced materials** offer, and factories of the future will need more advanced equipment to meet the requirements for energy efficiency and environmental



targets and to meet new demands for a connected world. The future will therefore see modern, lightweight, long-lasting/flexible and smart equipment able to produce current and future products for existing and new markets. There will be a step change in the construction of such equipment, leading to a sustainable manufacturing base able to deliver high-added-value products and customised production. Increased smartness in the manufacturing equipment also enables a systems approach with machines able to learn from each other and impacting on the human-machine interface.

6.3 Information and communication technologies

Among the major challenges that manufacturing companies face today are the growing complexity of their processes and supply networks, cost pressures, growing user and customer expectations for quality, speed, and custom products, and worker safety and assistance. Manufacturing is evolving from being perceived as a production-centred operation to a human-centred business with a greater emphasis on workers, suppliers and customers being in the loop⁴¹.

The foremost requirement for addressing these challenges is **collaboration**. In collaborative manufacturing, ICT will support a constant feedback loop without media breaks between product designers, engineers, state-of-the-art production facilities and customers. In **collaborative supply networks**, OEMs will be able to offer value-added services (e.g. maintenance, upgrade) or even sell their 'products as a service'. Remote service management helps to improve equipment uptime, reduce costs for servicing (e.g. travel costs), increase service efficiency (e.g. first-visit-fix-rates) and accelerate innovation processes (e.g. remote update of device software). Through **customer collaboration** future ICT solutions would enable extraction of customer and after-sales information from sources such as the social networks and feed this information to develop personalised and customised end-products of the future.

Connectivity is inherent to the development of the future workplace. Manufacturing processes should seamlessly and bi-directionally interact with real-world objects and environments on a global scale, across a variety of application domains and stakeholders, thus realising the 'Internet of things'. Workers' direct interaction with physical systems will enable processes that are real-world aware, event-based, and significantly more adaptive than today's processes, which will result in increased visibility, responsiveness, and safety in the workplace of the future. Enterprise Information Systems (EIS) have to be opened up and made highly reliable to facilitate global collaboration across multiple organisations similar to the services offered on today's Internet. Globally accepted standards, methods, and tools have to be developed to enable large-scale infrastructures that can be configured, integrated, and monitored efficiently. Intelligent systems with advanced self-configuration, self-monitoring, and self-healing properties are required to manage the large and fast growing number of devices. One of the biggest challenges for connectivity is that of security. Different stakeholders with varying business interests and hierarchy will access the product, production, and customer data outside enterprise boundaries to accomplish various manufacturing operations.

Mobility will play a pivotal role in the workplace of the future by arming both workers and supervisors with critical data at their fingertips. ICT needs to focus on infrastructure

⁴¹ ICT for manufacturing, The ActionPlanT Roadmap for Manufacturing 2.0.

mechanisms beyond pure connectivity that support manufacturing business needs (e.g. flexible manufacturing cloud services for storage and computation, robust and efficient security and payment mechanisms as well as means of dedicated information gathering and process analytics). Furthermore, the next generation of mobility-assisted manufacturing applications such as manufacturing and logistics traceability, product genealogy, cross-channel product distribution, and 'manufacturing app stores' should be developed.

Lastly, ICT research in manufacturing **intelligence** will assimilate the huge amount of data originating as a result of increased collaboration and connectivity and render meaningful information on-the-fly on mobile devices for managers and shop floor supervisors. Progress beyond the state of the art in complex event processing, real-time data analysis, and forecasting of complex scenarios originating in workplaces of the future needs to be made. Research, development and innovation (RD & I) in this area aims at providing full transparency across all stages of the manufacturing process. This transparency is required to optimise operational efficiency, and guarantee seamless tracking, tracing, and compliance. Currently, most business intelligence systems only allow the user to analyse this data in reporting mode; however, with in-memory technology future manufacturing enterprises will be able to analyse and 'play with' data in real time.

All solutions of the future should inherently be more sustainable by offering ways to reduce energy consumption, increase sustainability and reuse through the use of reconfigurable modules. A lot of attention is dedicated to the development of technologies that help maximise the impact on SMEs with the goals of giving them access to affordable and high-yield modern production technologies, and industrialising them rapidly to deliver innovative products at competitive price advantage.

A major impact is expected from the following technological areas:

- **ICT solutions for factory floor and physical world inclusion:**

Real-world resources such as machinery, robots, lines, items and operators are an integral part of the information structure of production processes. All of them need to be connected to each other and to back-end systems and at the same time to be self-aware of the surrounding environment.

- **ICT solutions for next generation data storage and information mining:**

A copious amount of data from the field and supply chain needs to be stored in a fault-tolerant way. Information embedded within these data needs to be elicited and made available. New ICT solutions will allow complex queries on distributed and heterogeneous data sources to be run in fractions of a second. Business intelligence tools for complex data stream analysis facilitate real-time decision-making across all tiers of the enterprise.

- **ICT solutions for implementing secure, high-performance and open services platforms:**

Distributed and collaborative applications will be implemented through 'mash-ups' of services implemented by different small and large ICT and manufacturing vendors. The cloud will be the meeting place for provisioning customised functionalities through services that are reliable, secure, and guarantee performance. Open standards will ensure the full inter-operability in terms of data and applications.

- **ICT solutions for modelling and simulation tools:**

Complex environments need to be consistently described by semantic models in order to correlate information, describe the dynamics, and forecast their behaviour. Knowledge from different sources (e.g. human, experience, research) will be made available and fully exploited by dedicated modelling and simulation tools. Here the main priorities are concern-integrated simulation techniques (product–process–production systems) and specifically:

- integrated knowledge-based systems supporting the product and process archetypes approach, with self-learning capabilities for semi-automatic design rules update;
- modelling and simulation of production process constraints influencing the characteristics and performances of the materials;
- modelling and simulation methods of manufacturing processes involving mechanical, energetic, fluidic and chemical phenomena;
- CAE models interoperability to allow fast and complete complex process of virtual verification;
- integration of the modelling and simulation methods of manufacturing processes in a MDO (multidisciplinary design optimisation) to permit a holistic approach and to guarantee fast and costless results.

- **Collaborative and decentralised application architectures and development tools:**

In extended enterprises and globalised markets, applications (e.g. life cycle management, supply chain management, monitoring and control, and customer relationship management) will no longer operate in closed monolithic structures. Stakeholders and customers collaborating on a common application platform implemented with the cloud approach will bank on new software development and testing environments more oriented towards non-technical users and support development of business processes. Distributed applications with low footprints targeting a large user base would be supported by enhanced business process re-engineering tools for rapid development and deployment.

6.4 Manufacturing strategies

Research and innovation for the Factories of the Future is not only a matter of developing and integrating novel technologies. Manufacturing challenges can only be properly addressed if the manufacturing community understands the mechanisms to create value. ‘Thinking outside of the box’ is not only required for generating technological innovation, it is also required for generating new approaches to operating supply chains and addressing markets. These innovative approaches and value-creation mechanisms are referred to as the manufacturing strategies for the factories of the future.

The most relevant approaches are:

- **From delocalisation to Globalisation 2.0**

The rise of transport costs, the need for higher efficiency and productivity, customer demand for greener products, the higher instability of raw material and energy prices and the shortening of the lead-time for production will push for a more critical assessment of the delocalisation strategy towards low-cost countries.



Service-led personalised products will require a new paradigm for western countries' reindustrialisation (Globalisation 2.0), bringing back manufacturing of selected products. This requires fostering the interaction between large enterprises and SMEs, creating European manufacturing networks.

- **From product/services systems (product-centred approach) to services through product (solution-oriented approach)**

The 'servitisation wave' of manufacturing has already spread out to the 'advanced' countries and many leading high-capital investment sectors (e.g. aerospace and automotive) are already competing in the international markets by providing to their customers a composition of services for product operation (e.g. maintenance, reliability, upgrades), and end-of-life use (e.g. re-manufacturing, recycling, disposal). SMEs, in particular, are trying to compete in the international markets with their niche solutions, adding innovative services to their value propositions. Such innovative business models are based on a dynamic network of companies, continuously moving and changing in order to afford more and more complex compositions of services. In such a context, there is a strong need to create distributed, adaptive and interoperable virtual enterprise environments supporting these ongoing processes. In order to do so, new tools must be provided for enabling and fostering the dynamic composition of enterprise networks. In particular, SMEs require tools and instruments which follow them in their continuously reshaping process, enabling collaboration and communication among the different actors of the product-service value chains. New IPR methods are also needed.

- **From user-centred design to user well-being design**

According to the new paradigm of sustainability, the importance of the user is increasing. The user is at the same time a customer, a citizen and a worker. The well-being of the user could therefore become a winning strategy both for business-to-business (B2B) as well as business-to-consumer (B2C) companies.

More detailed modelling behaviour can help the development of innovative solutions, aiming at user comfort, safety, performance, style; this requires new competitive focus for the development of these innovative solutions and new business models to support a quick and dynamic response to market changes.

- **Virtualisation and digitalisation of the interrelation between manufacturing and new business models**

As products are today virtually designed and tested before being engineered for production, new business models need also to have tools to support the company to design and test them before they are implemented through products, services and manufacturing processes. The complexity of these tools is higher than that of tools for product development, due the need for holistic modelling of product and processes.

- **Innovation**

Finally, innovation should become a business model in itself and a continuously run business process (the factory innovation): increasing the competitiveness through the design of a new product requires the development of a company strategy where product and process innovation is seen as a permanent, widely distributed, multi-level, social-oriented and user-centred activity. Collaboration among companies of different sectors to exploit multi-disciplinary cross fertilisation is also envisaged. New tools, methodology and approaches for user experience intelligence (i.e. social networks, crowd sourcing, social science methods, qualitative and quantitative, to generate insights, models and demonstrations, etc.) need to be addressed and explored.

6.5 Modelling, simulation and forecasting methods and tools

All previously mentioned enablers are reinforced by the capability of simulating manufacturing process or forecasting the behaviour of manufacturing systems and processes, be it during the design phase or during their operational phase. Advances in ICT in terms of computing power, communication speed or multi-modal visualisation are moreover enabling the further development of simulation and forecasting tools.

- **Modelling and simulation for the (co-)design and management of integrated product–process–production systems**

Achieving the goal of sustainable manufacturing requires methods and tools for modelling, simulating and forecasting the behaviour of production processes including the processed materials, resources, systems, and factories during their life cycle phases. New methods and tools are needed for the multi-stakeholder co-design and management of integrated product–process–production systems that are well embedded into their social, environmental and economical context.

- **Virtual models spanning all levels of the factory life and its life cycle**

A holistic and coherent virtual model of the factory and its production machinery will result from the contribution and integration of modelling, simulation and forecasting methods and tools that can strategically support manufacturing-related activities during all the phases of the real factory life cycle (e.g. site and network planning, conceptual design, technology selection and process planning, resource design and

component selection, layout planning, implementation, ramp-up, operation/execution, maintenance, end of life).

Virtual factory models need to be created before the real factory is implemented to better explore different design options, evaluate their performance and virtually commission the automation systems, thus saving time-to-production. Furthermore, virtual factory models will be maintained throughout the lifetime of the production to guarantee an effective and efficient connection with the shop floor. On the one hand, reconfiguration options need to be tested in the virtual factory thanks to modelling and simulation tools and then, after validation, implemented into the real factory in a shorter time. On the other hand, the evolution of the real factory will be reflected and stored in the virtual models of the factory.

Modelling, simulation and forecasting methods and tools for manufacturing may have a great impact on the **whole factory hierarchy**. At the low level of the hierarchy, methods and tools can improve the design and management of production machinery and processes to support advanced and sustainable manufacturing. Methods and tools are required to properly design and manage production systems that are becoming more and more complex. Finally, at the high level of the hierarchy, modelling and forecasting are needed to support long-term strategic decisions.

6.6 Knowledge-workers

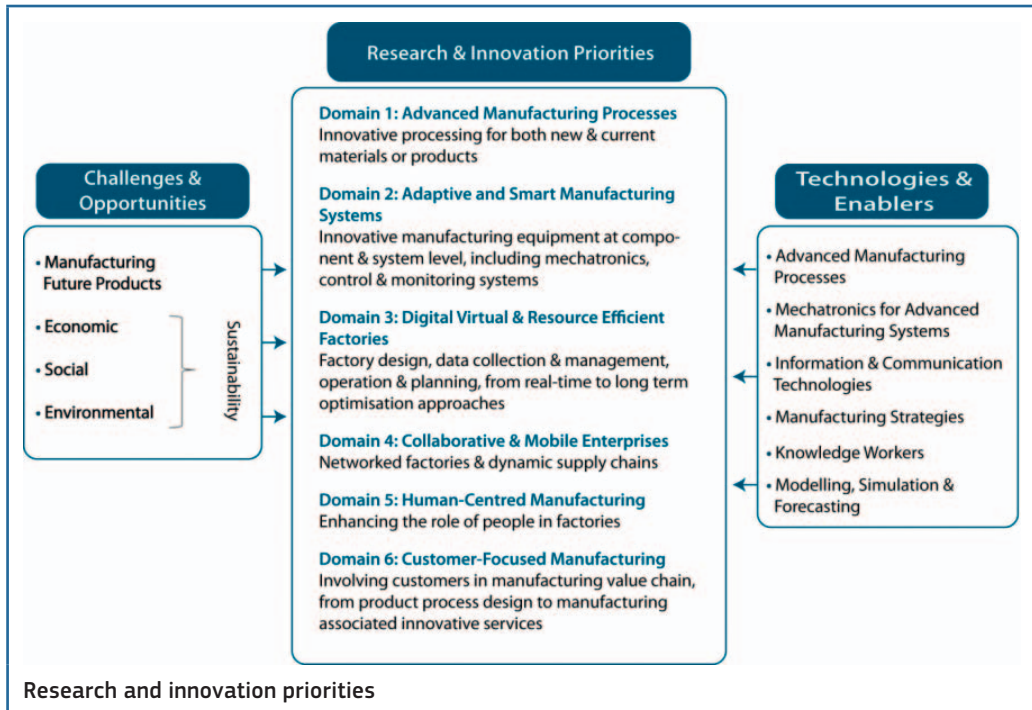
The European Factories of the Future are not only expected to provide global manufacturing competitiveness, but also to create a large amount of employment opportunities for citizens. Future factory workers are therefore key resources for industrial competitiveness as well as important consumers. However, as previously stated, the changing demographics and high skill requirements faced by European industry pose new challenges. Workers with high knowledge and skills ('knowledge-workers') will be a scarce resource.

Research efforts within Horizon 2020 must address ways to increase the number of people available for, and interested in, manufacturing work. This includes the following important aspects of the human resources:

- New technology-based approaches to accommodate age-related limitations, through ICT and automation;
- New technical, educational, and organisational ways to increase the attractiveness of factory work to the young potential workforce, the existing workforce, the potential immigrant workforce, and the older workforce;
- New approaches to skill and competence development, as well as skill and knowledge management, to increase competitiveness and be part of the global knowledge society;
- New ways to organise and compensate factory knowledge-workers;
- New factory human-centred work environments based on safety and comfort;
- Ways to integrate future factory work into global and local societal agendas and social patterns.

7 Research and innovation priorities

Research priorities address manufacturing challenges and opportunities and identify which technologies and enablers should be developed and deployed. They are organised in domains, some of which are further organised in sub-domains:



7.1 Domain 1: Advanced manufacturing processes

The set of research priorities under this domain focuses on innovative processes for efficient and high-quality manufacturing for either both new and current materials or products. The emphasis of new materials and to some extent existing materials is on manufacturing at scale, whilst achieving the flexibility and responsiveness needed to accommodate changes in market demand. Products of the future are expected to be more complex (3D, nano-micro-meso-macro-scale, smart), so processes need to handle complexity and enhanced functionality whilst not adding or at least minimising cost. Micro- and nano manufacturing in particular demand specific approaches for intelligent, adaptive and scalable systems.

Sub-Domain 1.1 Processing novel materials and structures (into products)

7.1.1 Manufacturing for custom-made parts

Customisation is a key differentiator within high value manufacturing, to provide competitive products and deliver new services and localised functionalities. It requires new strategies to be developed, integrating design with manufacturing and incorporating appropriate control methodologies to ensure small or large lot quantities which meet the specifications. Examples include new custom-made parts or spare parts on demand either to sub-divisions of sectors/products or personalised to an individual as well as unique identification marking of products. Processes need to be developed which are flexible at the local level to meet specific customer demand and mass customisation where rapid translation between different specifications is required.

Advanced manufacturing processes will enable new ways to address customisation, so processes need to enable manufacturing of multi-materials/functionally graded materials, flexibility and rapid change (e.g. laser processing, additive manufacture, modular tooling, direct fabrication with no tooling, near-net shape methods or processes, tailor blanking). Equally, developments in materials will provide for optimal topological features, added functionality and levels of personalisation not previously possible at scale. Examples include printing inks/processes, on-demand (nano)coatings, use of different materials or sandwich materials. Approaches that exploit new capabilities for application within a central factory or deployed at local sites should be explored.

For all custom manufacturing it is necessary to have quick realisation from design to production in one process step as well as economic production systems down to single and small lot sizes. Research should also address the need for seamless data integration across the process chain (e.g. CAD, production planning, simulation and process).

7.1.2 Advanced joining and assembly technologies for advanced and multi-materials

Advanced and multi-materials provide Europe with an opportunity to create new products able to operate in more extreme environments (deep sea, space, engines, medical) but it is important to retain the performance such materials offer in their final product form.

Joining and assembly are key enablers for the incorporation of new and advanced materials into structures, particularly where their use is restricted by material cost or functionality requiring the use of multi-material and modular structures (including actuation, sensing). Using welding, joining and assembly as a means for modularisation and efficient use of such materials can accelerate their adoption into products.

Alternatively, joining with its introduction of heat, other materials or geometrical changes, can lead to loss of performance, thus cause-effect relationships and materials process interactions need to be understood and controlled to maximise final product performance (e.g. through determination of material parameters for structure simulation and faster design, simulation models and failure principles, development of analysis methods (stiffness, strength,

corrosion ...). Development of such relationships can enhance structure simulation and enable faster design.

Maximising material performance and hence material efficiency will require improved, new or hybrid joining technologies. Alternatively, new materials will need to be integrated with other materials (e.g. dissimilar metals, composites with metals, textiles with electronics) through clever use of joining and assembly technologies. High productivity and 'self-assembly' technologies are other challenges to reduce operational cost and to improve manufacturing competitiveness. In order to be competitive in the future, these novel joining and assembly technologies should be implemented with a high degree of automation and quality control with self-organising processes to accommodate complexities and accuracies.

Practical validation of the new processes needs to be determined on demonstrator work pieces or early stage prototypes. The latter should be supported by appropriate simulations of both equipment and manufactured parts.

7.1.3 Automated production of thermoset, and ceramic thermoplastic composite structures/products

Composites have not delivered to their full potential even in the more established aerospace sector, but there are also increasing demands in other sectors for weight reduction such as for electrified cars and novel constructs as may be required for the medical sector. New manufacturing methods and concepts which will help to reduce cost and exploit the unique properties of composites are needed, including: automated production of composite structures/products; novel resins and polymer matrix combinations; high-efficiency manufacturing of ceramics and ceramic-metal composites; non-autoclave manufacture; hybrid manufacturing for multi-material composites; accelerated cure; automated lay-up for large structures; press forming and welding of thermoplastic matrix composites; new tools such as lasers for cutting and joining.

In order to achieve a higher degree of automation and reliability, flexible automation adaptive control solutions and adequate quality control concepts have to be developed. The reuse and recycling of composites is not fully addressed today, so processes that enable and explore procedures and reuse of such materials will be essential as their use grows, in compliance with other sustainability priorities.

Practical validation of the new processes needs to be determined on demonstrator work pieces and pilot plant production.

7.1.4 Manufacturing processes for 'non-exhaustible' raw materials, biomaterials and cell-based products

The bio-based economy will have a disruptive impact on all manufacturing operations in Europe. Sourcing will need much greater flexibility and new raw materials must be adapted to meet the speed of change required. The next generation of materials will exploit nature's renewable biological resources, to some extent reducing the scarcity of existing engineering materials (less dependence on exhaustible materials such as fossil carbon) as well as addressing environmental issues through recycling, energetic valorisation or, if a better option, biodegradability. As these materials demonstrate real value for industrial, energy, construction

and health products, there is a need to develop smart manufacturing processes that can work with less defined and controlled types of materials yet are endowed with unique properties such as self-assembly to deliver new controlled, predictable products for exploitation into new (and existing) markets. Processes must take into account GMP (good manufacturing practice) as needed for biotech and cell-based products whilst ensuring flexibility with batch or continuous production. Innovative manufacturing approaches which take account of nature's own evolution and enable better design of product (biomimetics) or improved capability through self-healing, for example, are relevant to enhance European capability in this area.

Today's established recycling systems will change and become a future value chain in another sector. This will put a tremendous adaptability pressure on the manufacturing processes and in particular biological productions will experience major changes in their business models. Future automated solutions must be able to handle much higher variation and refitting must be inline. Future automation will therefore not only include small, flexible robotic solutions, but also intelligent integrated systems based on advanced sensors provided by a broad range of technologies such as ultrasound, 3D-vision, CT-scanning and tactile feedback solutions.

7.1.5 Delivery of new functionalities through (mass production) surface manufacturing processes

The ability to design in functionality through surface modifications, functional texturing and coatings, enabling improved performance, embedded sensing, adaptive control, self-healing, anti-bacterial, self-cleaning, ultra-low friction or self-assemblies as examples, using physical (additive manufacturing, laser or other jet technologies, 3D printing, micromachining or photon-based technologies, PVD) or chemical approaches (CVD, sol-gel) will deliver high functionality and hence high-value products. Special attention should be paid to the flexibility of novel manufacturing surface processes and to the development of easy-to-transfer and low-cost technologies. Novel technologies and approaches are needed to embed true smartness into structures and scale-up of all processes is of equal importance. Specific requirements exist for the medical sector including implants where new functionalities are needed and have to be manufactured in clean conditions to tight regulatory requirements.



There is also the need to address coating methods which today are widely used (wet chemistry, electro-chemical) but may have environmental or other challenges. This can examine radically different approaches to the existing methods or new alternatives.

Sub-Domain 1.2 Complex structures, geometries and scale

7.1.6 Material-efficient manufacturing processes

A major challenge for manufacturing is how to produce more using fewer resources. This has two key approaches, firstly how to save materials through new manufacturing approaches and secondly how to minimise energy consumption during manufacturing. The former will require new design approaches coupled with new, material-saving production processes with improved material efficiency and enabling the (flexible) use of substitute materials. Approaches might comprise near-net-shaped concepts (including additive (laser-enabled) manufacture), mimicking assembly of natural structures; re-manufacturing and recycling, novel use of waste streams; hybrid processes and improved process control and inline-inspection systems through supervision and control of the process parameters, pre-processing prognosis and proactive controls integrated with cognitive systems. The latter can exploit the use of novel, new or regenerative (i.e. Low C) energy supply, better use of waste streams through recovery and efficiency improvements in manufacturing equipment (e.g. throughflow speed).

Increasing the material efficiency can be developed at different levels of manufacturing system through: (i) process modification, (ii) on-site recovery and reuse of waste materials and (iii) transformation of waste into useful by-products. These actions will require a better understanding on various material efficiency measures and their interactions among different manufacturing processes and/or industries.

7.1.7 High-volume manufacturing at the micro- and nano-scale

The ability to produce highly integrated, functional 3D micro-products at medium to high volume (determined by market not technology) within a safe environment requires the development of conventional (forming, machining, heat treatment, replicating) and new manufacturing processes and related equipment — at the micro- and nano-scale, encompassing design, tooling, assembly, joining and reliability issues (e.g. fully integrated factory lines that merge nano-micro-meso-macro scale manufacturing). Methods for automatic handling of parts, in line metrology and inspection also require development to ensure ability to manufacture at scale with high reliability. The combination of different technologies to obtain the final product introduces system-level problems such as the transport of micro-parts, the coherence of the reference system in the different production stages and the integration of different machines into a system.

7.1.8 Robust micro- and nano-enabled production

In order to bring micro and nanotechnology-enabled products or manufacturing processes successfully and safely into the market, rigorous quality control systems are needed. They must provide the ability to analyse or measure in three dimensions with high resolution and absolute accuracy over large areas or with high aspect ratio on complex parts, in less temperature-controlled environments and a speed/throughput compatible with industrial standards (in situ control). Aspects of machining or manufacturing at nano-scale and the effect on production equipment and workers also need to be taken into account.

A systems approach is needed to ensure consistent and reproducible processes able to operate within the required limits for micro- and nano-production, monitoring and controlling machine performance, component handling and transfer as well as component accuracy.

Where needed, measurements in the nanometer range should be traceable back to internationally accepted units of measurement (e.g. of length, angle, quantity of matter, and force). This requires common, validated measurement methods, calibrated scientific instrumentation as well as qualified reference samples and a robust manufacturing of these reference samples. In some areas, even a common vocabulary needs to be defined. A traceability chain for the required measurements in the nm range has been established in only a few special cases.

7.1.9 Integrated manufacturing processes

Integration of non-conventional technologies (e.g. lasers, water jet, electro-discharge machining, ultrasonic, printing) towards the development of new multifunctional manufacturing processes (including in process concept: inspection, thermal treatment, stress relieving, machining and joining) will provide a means to reduce manufacturing time to market and increase the quality on the work piece. Demonstration of greater manufacturing efficiency whilst minimising use of raw materials and energy consumption are equally important. There is a wide use of such integrated manufacturing approaches across polymers, composites and metals-based materials as well as multi-materials. Where appropriate mechatronic approaches should be developed.

7.1.10 Manufacturing of high-performance flexible structures

Polymers, elastomers and advanced textiles are a large component of European manufacturing advantage, and new manufacturing methods and technologies are needed to realise the full potential of such high-performance materials increasingly used in applications such as transport, construction, protection, medical devices, flexible electronics and others. This will include efficient manufacturing of 3D structured, multi-layered and hybrid materials, joint-free realisation of complex shapes, automated joining and a wide range of surface engineering and functionalisation (coating) techniques. Combined benefits from processes, such as plasma, which can enhance functionality whilst also reducing energy consumption should be exploited.

Other flexible structures are also relevant where they offer significant potential for European industry, examples including food products.

Sub-Domain 1.3: Business models and strategies for disruptive manufacturing processes

7.1.11 Product life cycle management for advanced materials

Modern high-tech products adopted in the electronics, medical and energy industries are made of critical materials that are presently poorly recovered and reused and will potentially generate massive landfill needs in the near future. Such materials include advanced and rare

earth metals, composites (long and short fibre), nano-materials and bio-materials as well as more conventional materials that are not today considered for reuse due to absence of data on reprocessed performance. This unsustainable scenario focuses attention on systemic solutions to design, manufacture, monitor, maintain, reuse, re-manufacture and recycle these materials in the way that is already established for traditional materials and products. Such new systemic approaches should take advantage of the built in product 'smartness' and modularity to generate intelligence on ageing in electronic products as well as to make product disassembly and reuse easier to achieve. Moreover, new technologies and automation solutions should be developed for the effective separation (e.g. new fastener systems) and recovery of these materials. For example, the separation and recycling of resins and fibres from composites should be addressed. Another example is additive laser processes, which could be used to refurbish damaged parts instead of discarding them. Finally, new business models that consider different end-of-life options for making the closed-loop approach more economically attractive need to be designed and validated.

7.1.12 Novel supply chain approaches for innovative products

New supply chains which address globalisation and the integrated offering of product with service will demand new approaches, which take into account movement of material, exploitation of clusters of manufacturing excellence alongside an ability for local customisation.

The production of highly customised products with short life cycles addressing volatile markets will require new structures and operation strategies of their supply chains, comprehending sourcing, including land management as regards sourcing of biomass, and the management of the management of the EOL phase. Future supply chains will need to reconfigure dynamically as customer-specific products will be based on an increasing number of specific components. Therefore new technologies, structures and ICT systems are needed to establish ad hoc supply, manufacturing and de-manufacturing networks for customer-specific products, that support decision-makers in finding and establishing the best possible supply chain solution for any specific order.

Any new approaches need to develop appropriate cost models to quantify benefits along new supply chains (costs, environmental, etc.) along new supply chains, to help in making decisions and help during the design process of innovative products and encourage inform the translation to new ways of working.

7.1.13 New models for introducing disruptive processes

Disruptive manufacturing processes will often require a new approach at the system level to ensure maximum benefits are achieved through their introduction, rather than fitting such processes into existing factory environments. At one level, this will require appropriate models to evaluate the integration of new processes into a factory line, including cost models, and at the other will require design and implementation of evolutionary control strategies. Examples include demonstration of overall cost savings for implementation of additive manufacturing, taking into account new abilities to customise products, and how to ensure robust measurement and control systems accommodate new nano and biotechnologies, where in some cases the product being manufactured is biological and/or at very small size. Models and validation methodologies could also address the through-life performance of advanced materials in complex structures.



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7.1.14 Photonic process chains

Photonic tools can provide ways to new process chains and take account of the growing ‘system relevance’ of photonics for production and product planning. Therefore, research should aim at greater integration of photonic production, from computer design to quality-controlled products: ‘from digits to photons to items’.

‘Photonic process chains’ should essentially cover the intelligent linking of photon- (and non-photon-) based manufacturing processes with upstream processes including product planning, design and construction, measurement and post-production and logistics processes for the manufacturing of complex or customised products. This includes, for example, adaptive production concepts based on intelligent laser networks and optical sensor and control systems. A focus should also be on generative photonic processes (layer-by-layer production of complex components by laser from the raw material, e.g. 3D-printer) which are readily available in the first generation and can produce geometries — e.g. for lightweight design — that are not feasible with conventional tools. Photonic process chains could further support the trend toward flexible production of material products directly from digital data.



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7.2 Domain 2: Adaptive and smart manufacturing systems

The set of research priorities under this domain focuses on innovative manufacturing equipment at component and system level, including mechatronics, control and monitoring systems.

The research priorities recommended under this domain aim at future European manufacturing systems and processes that adapt in an agile manner to varying market and factory demands thanks to intelligent robots and machines that cooperate both among themselves and with persons in a safe, autonomous and reliable manner.

Sub-Domain 2.1: Adaptive and smart manufacturing devices, components and machines

7.2.1 Flexible and reconfigurable machinery and robots

Development of innovative ICT tools for supporting the as-autonomous-as-possible reconfiguration of machinery and robots, as the basis for supporting mass customised and highly

personalised products and fast reactions to shifts of market demands. Expected tools will address challenges related to simulation and monitoring of material and energy resources consumed in these reconfigurable systems together with their self-adjustment, correction, and control as well as the networking among them, aiming at a significant impact of changeover time/cost, tooling, programming and energy usage of those systems. Research should include aspects such as improved methods for engineering process, communication structures and generic resource description for 'plug-and-play' machine integration.

7.2.2 Embedded cognitive functions for supporting the use of machinery and robot systems in changing shop floor environments

This concerns the development of embedded cognitive functions for supporting the use of machinery and robot systems in less/partly structured shop floor environments. More advanced sensing and perception, combined with robust behaviour with respect to unforeseen changes is needed for machinery and robot systems that must perform well over increasing uncertainty ranges. In addition to this, an important aspect to be addressed is also the development of self-monitoring and self-healing capabilities of machinery. Expected methodologies and tools will address challenges related to sensing and perception, control, integration and networking among cognitive machines and robot systems, aiming at a significant impact of changeover time/cost, tooling, programming and energy usage of those machines and systems.

7.2.3 Symbiotic safe and productive human–robot interaction, professional service robots and multimodal human–machine–robot collaboration in manufacturing

Immersive and symbiotic collaboration between human workers and robots leads to a more efficient and flexible manufacturing environment. Cognition-based intelligent features and prediction-based reactive control strategies within machinery and robots will radically change their interfacing towards human workers in manufacturing environments in such a manner that the human–robot–system will be dynamic, will safely act in a shared working space, will follow an intuitive cooperation and will be aware of its work and of its environment. Moreover intuitive and multimodal task-oriented programming devices will make the machines capable of understanding human-like instructions, increasing interaction efficiency.

Semantics, reasoning, self-learning, social awareness and decision-making capabilities for these smart and autonomous robots interacting with other robots, with machinery and with human workers as well as distributed embedded real-time systems should be investigated, with capability to analyse large volumes of sensory data. Expected methodologies and tools will address technical but also normative challenges.

7.2.4 Smart robotics — scaling up for flexible production and manufacturing

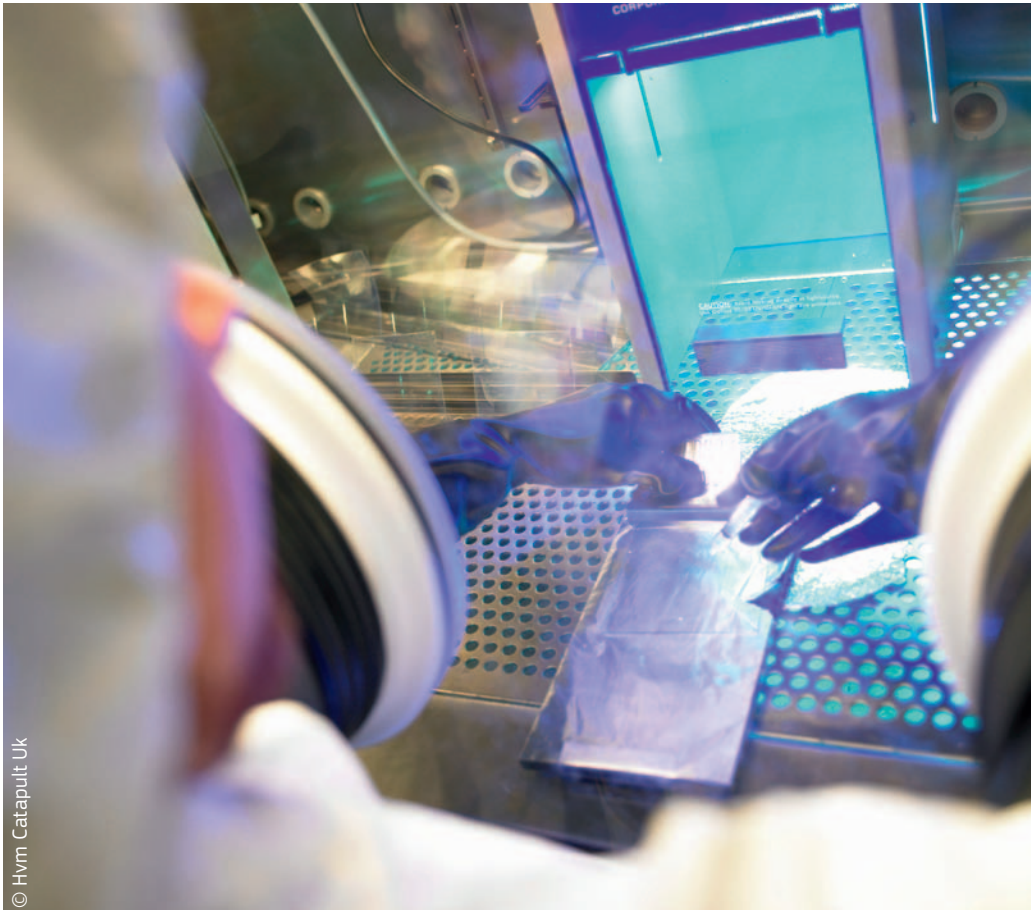
In order to achieve a wide and successful implementation of innovative robotics solutions in manufacturing environments, in particular in SME companies, trialling and validation activities are required. These actions will perform system integration of intelligent robotics functions and solutions resulting from more upstream research in industrially relevant manufacturing environments.

7.2.5 Mechatronics and new machine architectures for adaptive and evolving factories

Within a context of quick changes in terms of production types and volumes, easily upgradable and reconfigurable machine/cell/plants are important to achieving flexible and responsive manufacturing processes. In this regard, manufacturing systems should be conceived from scratch as combinations of smart and exchangeable mechatronic modules, thus taking the most out of a combination of electro-mechanical and embedded and learning controllers for adapting the system behaviour to changing environments and system degradations. This modular vision for adaptive machines should be duly complemented with robust industrial real-time communication technologies, system modelling approaches and distributed intelligence architectures, so that machines are capable of adapting to variable circumstances, thus leading to adaptive and evolving factories.

7.2.6 Mechatronics and new machine architectures for high-performance and resource-efficient manufacturing equipment

With the aim of ensuring competitiveness of manufacturing companies in a sustainable manner, the goal of high performance and reliability of manufacturing equipment must be achieved with a minimum of environmental impact combined with a minimum of economic costs. In



this view towards competitive and eco-efficient manufacturing equipment, machine concepts could be reconceived from scratch, by integrating at conception stage multi-disciplinary and synergetic technologies such as new machine architectures, redundant feed-drives, active machine elements, innovative structural concepts, smart actuator systems like tactile grippers and smart locking devices, haptic feedback control sensor-actuator-units for robust, reconfigurable manual switches in clean continuous surfaces, etc. Resulting 'avant-garde' manufacturing equipment should comply with requirements coming from manufacturers with maximised throughput and minimised total life cycle environmental and economic costs.

7.2.7 Micro-precision into micro- and macro-production equipment

High-precision manufacturing and micro-manufacturing oblige precision manufacturing to increase with one order of magnitude the accuracy of conventional machines and controls. The issue is that this requirement of extremely high precision can arise both in micro and macro-production environments. Therefore, new machine conception approaches together with innovative technologies are required to enable manufacturers to achieve high quality and high precision in manufactured products that can range in their size from a few microns up to several metres.

7.2.8 High-performance and resource-efficient manufacturing equipment by applying advanced materials

Innovative advanced materials with improved functional performance such as wear and hardness have the potential to generate significant advances along the life cycle of production equipment: at design stage, a reduced consumption of resources may be achieved through materials such as advanced metallic and composites as well as high performance plastics and textiles. At the use stage, benefits such as higher performance, easier system reconfiguration, lower energy consumption, reduced pollution, increased durability and reliability at system and component level, high quality of manufactured parts and easier maintenance can be achieved, all this together with reduced total life cycle costs, both environmental ones and economic ones. This integration of innovative materials demands multidisciplinary approaches that integrate both the technologies linked to these materials with the technologies linked to manufacturing processes and systems. All this together with embedded sensing, memory and active elements, so that the resulting equipment maximises the added value with respect to the involved and consumed material resources.

7.2.9 Multi-disciplinary engineering tools for mechatronics engineering

Multidisciplinary modelling and virtual validation of manufacturing equipment at design stage, including system-level simulation of mechatronic systems and integration of models from different domains prior to any actual manufacturing step, is the key to ensuring proper performance of such equipment without involving unforeseen and undesired reactive maintenance actions during its life cycle. These models do not cover enough accuracy for ensuring engineers that undesired phenomena will not arise. In this regard, advanced models would be required for components at equipment level, that besides integrating several disciplines such as mechanics, control and thermodynamics, are capable of being adjusted and calibrated with actual data so that these engineering models are capable of taking a qualitative leap both in accuracy and reliability.



Sub-Domain 2.2: Dynamic production systems and shop floors

7.2.10 Adaptive process automation and control for a sensing shop floor

Intelligent ‘plug-and-play’ systems will feature sensing and actuator structures integrated with adaptive control systems and with active compensation features for fully optimising the performance of the manufacturing systems in terms of autonomy, reliability and efficiency along their life cycle.

These systems should include software capable of monitoring KPIs and life cycle parameters as well as data processing and data-mining technologies capable of extracting the knowledge and model of machine and process parameters across the life cycle.

7.2.11 Dynamic manufacturing execution environments for their smarter integration into dynamic and agile shop floors

Current manufacturing execution systems (MES) are static and do not adapt adequately to the dynamic and agility of evolvable production systems. The high dynamicity of future manufacturing systems requires a constant optimisation of quality and resource usage. In addition, the amount of knowledge extracted from automation level should be fully exploited by manufacturing execution systems. A new MES generation is foreseen to deal with this highly dynamic environment and more sustainable manufacturing through optimisation of knowledge-based systems and synchronisation with shop floor automation and supply chain management systems. This new generation should have condition-based, exploit experience, self-organisation of manufacturing equipment and have suitable control and ICT architecture supporting these features.

7.2.12 Monitoring, perception and awareness on manufacturing

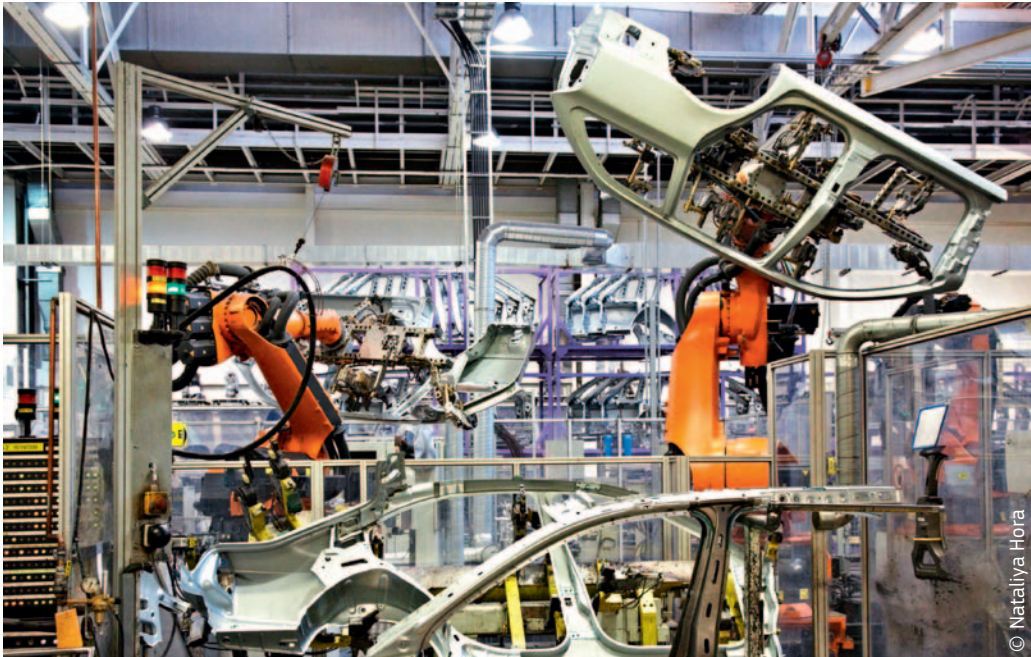
Within a view of high-value-adding manufacturing processes, it becomes essential to monitor the actual state of components and machines in a continuous manner, as a means of assuring diagnosis and context-awareness capabilities in the associated systems. In this regard, ubiquitous sensing approaches based on smart sensors and smart sensor networks will actively support engineers in their aim of detecting, measuring and monitoring the variables, events and situations which affect the performance, energy-use and reliability of these manufacturing systems and the production at factory level.

7.2.13 M2M cloud connectivity for future manufacturing enterprises

The problems of remote device management, high-volume data collection, and processing are going to become intractable in the future with the rapid proliferation of 'connected devices' across European shop floors. It is currently estimated that there will be in the order of 50 billion connected devices by the year 2020. European enterprises, particularly SMEs, are going to face difficulties monitoring their production assets across distributed plants and to calculate downtimes, MTBF, throughput, and other key performance indicators based on asset availability and exceptions. To cope with the challenges of distributed devices and high data volumes, future ICT research for manufacturing should leverage future cloud infrastructures to enable assets spread across distributed shop floors to transmit status and exception information which can be processed on-the-fly by persistency engines and rendered on workstations and smartphones of decision-makers. Research should be pursued in the development of universal adaptors to interface devices with cloud middleware and translate data collected from them. Development of faster distributed publish-subscribe broker systems in the cloud for devices to subscribe to and consume data and real-time event repository based on fast in-memory processing technologies would make consumption and processing of device data faster and more efficient.

7.2.14 Intuitive interfaces, mobility and rich user experience at the shop floor

Future research should exploit new mobile and user experience technologies to enhance the working experience of the European workers. Rich multisensory interaction should also be considered to support and augment workers' capabilities. It is a well acknowledged fact that European enterprises need to cope with the issue of ageing workforce in the near future by equipping them with tools and mechanisms to work with ICT systems on the shop floor easily. Intuitive UIs that are based on recent advances in HTML5, gamification, haptic, tactile and other non-traditional interfaces not only offer the distinct advantage of being easy to use for ageing workers but also make the user experience more enjoyable. Research on this front should not only focus on building interfaces for new kinds of manufacturing applications but also on improving the UIs and experience of legacy systems. Future research should focus on the development of standardised UI libraries that incorporate easy-to-access symbols and buttons for aged workers and are also easy to incorporate in production systems. It is important to overhaul legacy systems by decoupling UIs from main systems logic, and incorporating modular approaches that can be extended based on new advances in UI layouts and languages. Furthermore, a feedback mechanism to capture user interactions and iteratively improve future versions of the system should be developed.



7.2.15 Mass customisation and integration of real-world resources

Current plant connectivity systems lack the ability to configure large number of real-world resources, which may include shop floor devices, production systems, backend business systems, and abstract representations of human resources and intangible objects, effortlessly in an automated manner. In order to model disparate resources, present-day systems administrators use legacy middleware to manually register and then configure them on an individual basis. The future lies in the development of IoT-based device integration middleware that are scalable and distributed in nature and do not require manual intervention to register and configure multiple shop floor resources having the same generic specifications. This would improve productivity across shop floors by reducing configuration time and provide an automated way to control different facets of the shop floor. Future research is needed in the development of a dynamic object-oriented model to represent classes and instances of real-world resources as well as semantics representations to model intangible assets on the shop floor. These should be coupled with the development of SOA-based distributed middleware with dynamic code deployment functionality and intuitive UI that give holistic views of resource layouts on the shop floor and configurations to the decision-makers.

7.3 Domain 3: Digital, virtual and resource-efficient factories

The set of research priorities under this domain focuses on factory design, data collection and management, operation and planning, from real-time to long-term optimisation approaches.

Factories are becoming much more complex, expensive, distributed and fast evolving than in the past and manufacturers are struggling to put management of factory life cycle management into practice. New paradigms in the way plants are designed and managed, leveraging

the best practices of enabling technologies, are required to cope with competition and sustainability-related issues.

In the factories of the future, assets and inventories together with production and assembly lines would be dynamically designed, configured, monitored and maintained. A prerequisite for advanced factory life cycle management is the availability of an integrated and scalable factory model with multi-level semantic access to features, aggregation of data with different granularity, zoom in and out functionalities, and real-time data acquisition from all the factory resources (i.e. assets, machines, workers and objects). At process level complex numerical models, like highly non-linear FEM models from multistage processes including temperature cycles and functional behaviour become more and more a part of the innovation cycle. Stakeholders should be able to drill down into any production area and observe throughput, quality and process behaviour, through correlated key performance indicators (KPIs) accessible via user-friendly interfaces adaptable for varying user roles and mobile platforms.

Factories designed in such a holistic and structured way will be more efficient in energy consumption and will provide a safer workplace. Standardisation of design and management approaches will make them easier to implement and cheaper to run. Availability and reliability of the factory will be increased by enhanced maintenance methods, allowing for more efficient production.

7.3.1 Integrated factory models for evolvable manufacturing systems

Factories are evolving faster than in the past and becoming more complex, expensive, and geographically distributed. Commonly used IT-backend systems are neither widely interconnected nor interoperable which makes holistic representation, monitoring and management of the factories difficult. The development of integrated scalable and semantic factory models with multi-level access features, aggregation of data with different granularity, zoom in and out functionalities, and real-time data acquisition from all the factory resources (i.e. assets, machines, workers and objects) will enable the implementation of support decision-making processes, activity planning and operation controlling and facilitate faster ramp up through decreased time-to-market for future factories. The semantic models should be holistic in nature and be able to represent all levels of production functions and equipment. For real-time data acquisition, the connectivity paradigm offered by the IoT should be exploited and complemented with mobile decision-making apps that will assist plant managers in getting a holistic overview of KPIs computed on collected data.

7.3.2 Intelligent maintenance systems for increased reliability of production systems

Complex and expensive production assets in conjunction with market requests for high quality products require novel maintenance approaches that are able to provision required capacity and production quality. Intelligent maintenance systems based on condition prediction mechanisms, RUL (remaining useful life) estimation, and analysis of machines' behaviour, operational parameters, and self-learning capabilities will lead to increased reliability, availability and safety in the entire production system. Furthermore, health (condition) monitoring will entail significant energy savings. Maintenance would increasingly take place before the failure occurs and when its impact is at a minimum. For this, predictive data analytics techniques should be developed to aggregate and process the massive amount of data captured by intelligent

devices from the field on-the-fly. Furthermore, improvements in the state of the art of complex event processing techniques for cause-effect and trend analysis are required that operate on multi-core processors leveraging in-memory computing principles. Development of condition prediction reference models would assist in the scheduling of maintenance operations together with manufacturing mobile applications with rich UIs that will give a holistic overview to decision-makers about automated maintenance operations.

7.3.3 Integrated high-performance computing in factory life cycle management

Increasing complexity, stronger market competition and higher investments in green plants are forcing factories to be considered as complex long-life products where different life cycle phases such as factory design, engineering, operation and decommissioning need to be carefully managed in a consistent manner. Such holistic factory life cycle phases have to be addressed using appropriate distributed, interoperable, and high-performance ICT tools which make use of advances in parallel and distributed computing to deal with simulations, analytics, and forecasting on large data sets originating from shop floors, plants, business systems, worker inputs and variable business factors.

ICT solutions for technical and historical data storage and knowledge mining for factory level operations are required that will analyse and process the data collected from an integration of factory information systems as well as product life cycle management solutions. For performing these high-performance simulation and analytics operations, 'Infrastructure as a Service' (IaaS) offered by cloud computing paradigms should be exploited in order to particularly assist SMEs that are constrained by expenditure in high-performance computing infrastructure.

7.3.4 Energy monitoring and energy management in future manufacturing enterprises

Improved energy efficiency in future Manufacturing 2.0 enterprises is an environmentally challenging issue which also makes business sense to the enterprise by resulting in cost savings. Energy savings areas in the production environment have to be considered from different perspectives: component level, field level, machine level, process level, intralogistics and plant level. The development of software-based decision-support systems as well as energy management, monitoring and planning systems will lead to overall reduced energy consumption, more efficient utilisation and optimised energy sourcing. These decision-support systems should also be complemented by rich and intuitive energy management mobile dashboards available to the decision-makers at plant and board levels of a manufacturing enterprise. Future distributed computing deployments, such as the cloud, should be leveraged to upload enterprise-specific energy consumption information to obtain compliance certificates from regulatory bodies.

7.3.5 Multi-level simulation and analytics for improving production quality and throughput

Distributed simulation systems offer good local optimisation outcomes but lack interoperability and holistic modelling options, especially for complex manufacturing systems. Integrated multi-level simulation and analytics will facilitate enhanced factory modelling by enabling views and interpretations from different perspectives that are aimed at providing stakeholders



with different representations of relevant information. Improving quality and throughput should be analysed together with the impact on environmental, economical and social performances.

Modelling and simulation models that take into account interactions between the different stages of the production chain must be generated to consider the whole life cycle and be able to optimise the final part quality and throughput considering the effect of each manufacturing step.

IoT-based continuous data collection from real-world resources (i.e. assets, devices, products) from the field and along the value chain in conjunction with appropriate simulation and data analytics tools will identify deviations between expected and actual results allowing early management of factory and production issues.

7.3.6 Services for continuous evaluation and mitigation of manufacturing risks

Complex production environments and pressure from social and statutory organisations require that risks (internal arising from production processes or machinery failure as well as external ones such as environmental or natural calamity) be continuously identified, ranked, managed and mitigated. The complex dimensions of production facilities, processes and materials call for creation of ICT-based risk management solutions for averting accidents and safety hazards that could have dramatic consequences for human lives and the environment. Prevention and risk mitigation are also desirable options compared to recovery and salvage after damage has been caused. On the ICT innovation side, novel modelling approaches for identifying secondary and tertiary-level risk factors coupled with fast analytics using in-memory technology for on-the-fly detection of exceptions are a prerequisite. Furthermore, tools to model KRI (key risk indicators) and rendering these (through push notifications) on mobile devices of decision-makers through dedicated mobile computing infrastructure are required. Furthermore,

cloud-based social networks (or enterprise-internal communities) could be developed to update exception status and health hazards/risks for the benefit of workers and decision-makers alike.

7.3.7 On-demand modular and replicative models for faster factory initialisation

Easy and cost-effective design, engineering and deployment of new production facilities are a prerequisite for competing on a global scale. Multinational enterprises that seek to cope with the growing market demand and customisation requests from customers should be able to set up distributed sites with replicated features and assemblies without being required to start from scratch. The definition of consistent description model of the production processes and resources, their relationships and logistics flow that are based on ontologies (or common semantics) annotating the different elements of a factory model, such as: (a) production flow, IT architectures, management structures and equipment behaviour description such as authorised operative ranges or geometrical or functional constraints; as well as (b) management of system dynamics, evolution over time in order to support maintenance models and end-of-life management, are required. In order to render these complex ontology-based replicative factory models, state of the art in high-performance computing in the cloud should be leveraged for the benefit of SMEs and large enterprises alike. The issue of standardisation of factory models and their subcomponents should also be addressed. When considering replicating factories, priority should be given to implications and adaptations due to different legal, social, economic and managerial frameworks.



7.3.8 Mobility suite for comprehensive factory performance and resource management

In the past ICT and manufacturing enterprises have sought to manage the operational characteristics of plants through disparate software solutions. This has given rise to monolithic stacks that do not integrate well with each other and where decision-makers and workers are 'drowning in data but starved for information'. Mobile computing offers a promising prospect to render the complete set of factory management information on the smartphones of decision-makers enabling them to monitor, visualise, control, and collaborate on day-to-day decisions and exceptions arising in European factory environments. A 'mobility suite'

for comprehensive factory performance management will not only make it easier for decision-makers to oversee and control operations but will also result in significant cost reduction of factory running costs. The suite will offer downloadable apps for selective monitoring and management functionalities across the plant. It will house a manufacturing app store that

can be accessed by manufacturing stakeholders, particularly SMEs, for downloading relevant management apps of their choice. Intuitive UIs that display the right data at the right time on decision-makers' mobile devices through an intermediate mobility infrastructure is furthermore a prerequisite for making the suite usable and productive.

7.3.9 System-oriented quality control strategies in multi-stage manufacturing.

Quality-by-design is becoming established as a development discipline in product development within many industries. As a prerequisite in successful innovation a deep understanding of consumer needs is mandatory but also fast and uncomplicated pilot production and ramp-up will underline the need for quality-by-design. This relates to future low-cost quality control, system adaptability and minimised consumption of raw materials.

Within this research priority integrated production and quality control strategies able to effectively achieve the desired production rate of high quality products need to be developed. They should include both tools to prevent the generation of defects at single stage level and tools to prevent the propagation of defects throughout the system stages. To this purpose, quality control tools should be supported by distributed online data gathering systems, online defect management policies (i.e. online re-work or work piece repair), inter-stage information and part flow control strategies and selective inspection policies to achieve higher control on the most critical stages in the system. The final aim is to achieve production system configurations that profitably exploit the quality/productivity trade-off at system level. In this context, integrated production and quality control strategies able to effectively achieve the desired production rate of high-quality products need to be developed. They should include both tools to prevent the generation of defects at single stage level and tools to prevent the propagation of defects throughout the system stages, as well as tools to adjust models to reality online and propagate process evolution.

7.3.10 Design and management of production machinery and processes

Simulation models that represent the interaction between a production machine and the related technological process including the processed material will be able to forecast productivity and part quality in front of varying environmental conditions and phenomena like wear and partial damage in mechanical components or tools and dies. They can support the development of innovative machines and processes, but also model-based control and monitoring systems that continuously supervise the machine and autonomously act to improve productivity and part quality, bringing innovative adaptation policies across the whole machine life cycle. The development of such detailed models will ask for a strong collaboration among machinery designers, industrial components suppliers and CAE software developers. In order to become applicable the reliability of the models in comparison with the real behaviour of the machinery and processes requires strong empirical evidence. Europe may exploit the opportunity of being the leader of such 'co-modelling' community, by adding value thanks to an intensive knowledge-exchange network.

7.3.11 Design and management of production systems in evolution

Modelling methods and tools are needed to support the configuration of production systems since the early conceptual design phase, where the selection of the production resources and

the development of the entire automation system are tackled. In this phase, different closed loop simulation instruments, visualisation tools, knowledge-based systems and optimisation algorithms should be applied and integrated according to the available set of data and the expected level of details of the configuration solution. After the implementation of the production system, the production system model and the corresponding performance evaluation methods and tools need to be continuously updated according to the actual system behaviour, so that the virtual factory environment can be continuously tuned along the evolution of the real factories.

Such virtual tools should support the definition of future adaptation logics grounding on the knowledge of the current status of the system, as well as system optimisation strategies based on possible future scenarios of the system, thus ensuring improved robustness in the automation system. Energy, resource efficiency and economic viability of manufacturing systems can be considered as important KPIs in this research domain.

7.3.12 Design and management of manufacturing strategies

Since factories are becoming more complex and are distributed and evolving faster, the development of integrated, scalable and semantic virtual factory models will enable the implementation of decision support tools and optimisation methods to address strategic decisions such as the location of a new production site, the production technologies to be adopted and their acquisition method, the selection of products and services to be offered in the market and the sustainable pricing policies to be practiced. These models should allow a fruitful interaction among all the relevant stakeholders of the design of manufacturing strategies.

Strategic decision are affected by uncertainty and therefore there is a strong need for forecasting tools that make use of statistical methods for analysing historical data and algorithms to evaluate future scenarios and suggest the best solutions, quantifying and managing risks at business model level. For example, while designing or improving a new product or service many possible scenarios need to be explored from choice of specifications, design, materials, 'make or buy' and suppliers, to manufacturing strategy (produce to order or make to stock), product usage (profiles of customers), product servicing (type of maintenance services proposed), and product recycling.

7.3.13 Integration of design methods and tools

Effective design and management of factories asks for the integration of methods and tools with contributions from the electrical, electronic, mechanical, and physical and software domains. This integration, combined with a highly educated engineering workforce, will lead to innovation in rapid machine and system engineering, thus increasing worldwide European competitiveness in manufacturing. The integration of methods and tools requires interoperability between the various models dealing with specific problem in the factory hierarchy.

The goal of interoperability asks for the development of an appropriate manufacturing framework and the development of enablers and technologies to address the following issues: the involvement of several actors with different competences and expertise, the management of a large amount of heterogeneous data, the need to create a heterogeneous cooperative environment. It is not only technical people who need to be integrated in the process but more general interaction among all relevant stakeholders of the design process should be made possible.

7.3.14 De-manufacturing factories

Environmental concerns and increasing scarcity of key-metals and rare earths call for new de-manufacturing approaches allowing intelligent reuse, re-manufacture and recycle materials and components. New integrated flexible de-manufacturing technologies should be realised, together with new business models comprehending reverse logistics processes and market approaches that make sustainable the EoL business. Solutions should comprehend process technologies, automation and control systems, as well as methods and tools for design and simulation of de-manufacturing plants along their life cycle, separation technologies and new equipment (fixed or mobile) for dismantling, repairing and rebuilding.

7.4 Domain 4: Collaborative and mobile enterprises

The set of research priorities under this domain focuses on networked factories and dynamic supply chains.

The trend of collaboration between multiple manufacturing enterprises is becoming essential for day-to-day operations of any manufacturing enterprise irrespective of its size. Both SMEs and large enterprises stand to gain from collaboration solutions in their network. As part of the extended collaboration paradigm, OEMs will be able to sell 'products as a service' and certified suppliers or subcontractors will be able to offer value-added services — such as maintenance or upgrades — to customers. So-called 'capability-based' contracts will offer use-based billing instead of requiring upfront investments in machinery by subcontractors. Remote service management will help improve equipment up-time, reduce costs such as travel for servicing, increase service efficiency — like first-visit-fix-rates — and accelerate innovation processes, for example by remote updating of device software.

Some outstanding challenges which future manufacturing enterprises will have to encounter through innovative ICT are the following:

- Facilitating secure data exchange for collaboration in design, engineering, services, and supply chain between multiple stakeholders;
- Visualisation and tracking of processes, delays, and inventory flow;
- Accommodating dynamically changing orders and requirements from customers and suppliers;
- Enabling subcontracting and mitigating hidden capacity risks associated with it;
- Encompassing new product take-back laws and asymmetric information distribution for closed-loop life cycle management and especially for end-of-life (EoL) services for products;
- Capturing complexity and multidimensionality of supply networks.

In addition to leveraging the collaboration paradigm, manufacturing enterprises of the future and stakeholders in their holistic value chain should shy away from building additional functionalities on top of an already heavy enterprise software landscape. Global market trends show that the practice of building monolithic enterprise software with significant runtime footprint and high maintenance for the install base is becoming obsolete. Instead, SMEs and large manufacturing enterprises are increasingly looking for solutions that are agile,

instant valued, real-time, easy to use, and platform agnostic. With this observation in mind, innovation for the future should be focused on making collaborative enterprises mobile such that decisions within the holistic value chain could be taken 'on-the-fly' irrespective of the location of the enterprise or the decision-maker through easy to use and innovative mobile manufacturing applications.

7.4.1 Cloud-based manufacturing business web for supply network collaboration

The 'manufacturing business web' (MBW) is envisioned as a cloud-based real-time and easy access middleware that will facilitate stakeholders in the future manufacturing supply network to consume end-to-end manufacturing services encompassing domains of customer collaboration, collaborative service management, and collaborative manufacturing. It will be a manufacturing service delivery framework, which at the same time will be secure, robust, and interoperable. An MBW deployment would open up possibilities to exploit the distributed infrastructure using the IaaS paradigm for performing high-performance simulation, forecasting, and analytics operations. The MBW should offer manufacturing service visibility, discovery, composition, mash-up environment, and metering capabilities, which in turn will open up new business possibilities for manufacturing service providers to earn revenue. Furthermore, such a distributed infrastructure deployment would facilitate dynamic service instantiation and consumption through a pay-per-use model whereby manufacturing service providers (IT vendors) as well as consumers (manufacturing enterprises) could come together and find new business opportunities for servicing operations in the value chain.

7.4.2 'End-of-life' (EoL) applications in a network of remanufacturing stakeholders

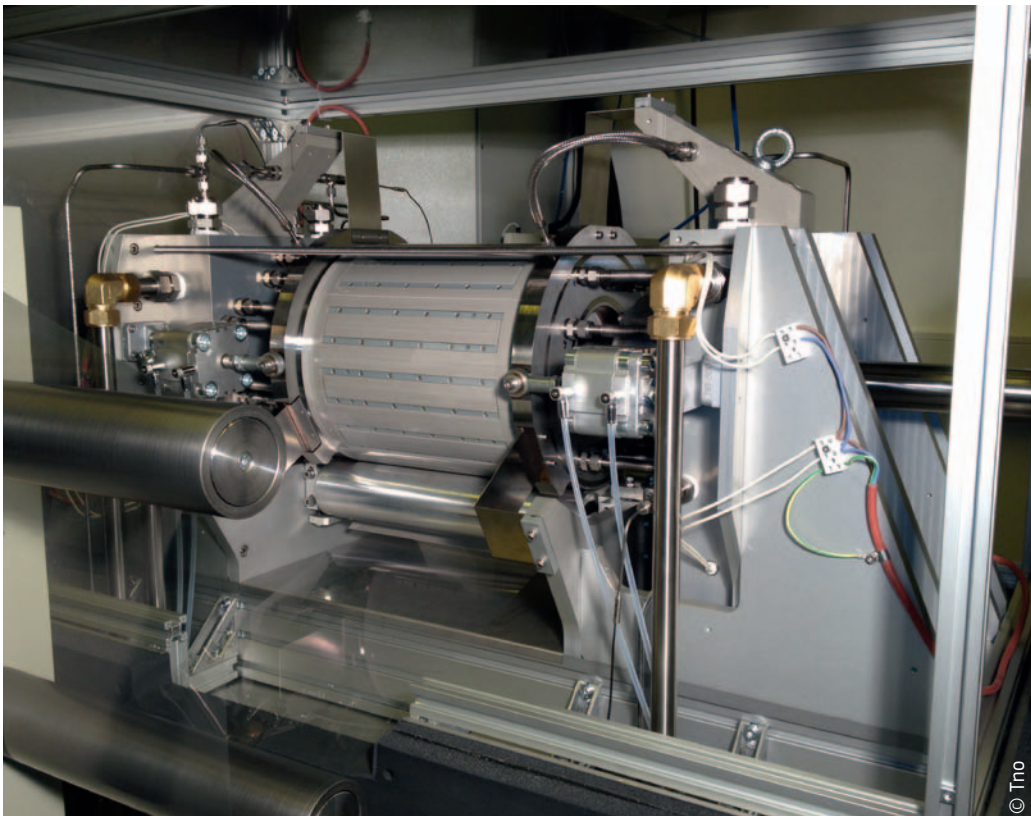
One of the key issues deterring the uptake of 'end-of-life' (EoL) activities such as re-manufacturing across Europe is the information gap that is created when new products leave the OEM, are then used by the customers, and eventually collected, disassembled and refurbished by re-manufacturing SMEs. The information gap is the result of the lack of data on product usage, repair, service, and refurbishment history. This, in turn, results in the fact that the input to the re-manufacturing process is of unknown quality. The lack of reliable information for re-manufacturing leads to opportunities being missed with respect to increased economic or environmental impact. In order to bridge this gap, research for EoL applications investigates enhanced and interoperable enterprise service bus architectures based on cloud (such as the MBW) for uniform data provisioning amongst EoL stakeholders. Unified product tracking and mapping schemes for identification of product cores and looking up of corresponding data and services associated with EoL products is also a key area of research. Lastly, optimal KPI calculation engines to assist OEMs and re-manufacturing subcontractors in making informed decisions about product reuse and mobile apps available to enable mobile tracking of usage and maintenance information for EoL products would be a step forward for ensuring sustainability and additional revenue generation through EoL practices. In order to maximise the recovery of materials from waste, the EoL platform leveraging the cloud and using predictive analysis of data from various sources will identify the needs of developing new industrial solutions (mechanical equipment, sensors, coding systems waste).

7.4.3 Mobile store and applications for an agile and open supply network

The responsiveness of stakeholders within a supply network can be increased and new business opportunities could be generated if the right kind of data is made available to the decision-makers at the right time 'on-the-fly' and 'on-the-go'. The next generation of ICT research in manufacturing should avail of the combined power of cloud infrastructures and mobile devices to render data from shop floor, production systems, as well as disparate business systems across the holistic supply network to human stakeholders and decision-makers. This research priority focuses on building a manufacturing-focused mobile provisioning infrastructure that will leverage the cloud and provide services via a manufacturing app store offering several key advantages: (a) data rendered on mobile devices which will facilitate quick decision-making thereby reducing missed opportunities; (b) manage-by-exception and alert monitoring will save revenue and resources; and (c) manufacturing app store to be a one-stop solution for SMEs and large enterprises.

7.4.4 Connected objects for assets and enterprises in the supply networks

Manufacturing 2.0 enterprise assets and products of the future will leverage the concept of the IoT where objects (and/or their related transport unit) carry information about themselves, communicate with each other and the world around them, in particular with the relevant intra-factory processes. In order to harness the potential of connected objects and perform meaningful data analytics, future research should bridge the gap between different abstractions of objects operating at the shop floor level, business systems level, and at the level



of supply networks. On the shop floor level, the need for research and standardisation of interfaces includes both mechanical (types of load carriers in relation to standardised types of pallets and, beyond them, to common means of intra-factory transportation like mobile machinery) and digital (programming languages, I/O protocols I/O devices in relation to common information carriers like bar codes, RFIDs and others) interfaces.

Furthermore, research has focused on how to ensure interoperability (standardisation, protocols, data and information models) between objects. This research priority will help realise the vision of 'product-centred services' through the manufacturing business web (through 7.4.1) where SMEs in the supply network would be able to offer maintenance, warranty, and EoL services to customers. Cooperating objects will carry their own servicing and maintenance information, thereby facilitating faster fault resolution and triggering repair operations. Furthermore, scalable tracking and tracing of production orders, assets, products and personnel across different organisations, semantic modelling and description of IoT resources, and business process modelling of data and interactions of IoT resources and capturing non-deterministic and unpredictable behaviour at run-time should be researched.

7.4.5 Complex event processing (CEP) for state detection and analytics in supply networks

Connected objects representing IoT in supply networks will give rise to a copious amount of data generated in the form of events. These events will be distributed in nature and display



the characteristics of non-determinism and asynchrony. Global state detection, time-to-event transformation, and discrete/continuous query processing would therefore be a challenge in view of the distributed nature of events. Future ICT research in complex event processing (CEP) should devise solutions for more responsive supply networks with capability for comprehensive monitoring and management of events, exceptions, and 'what-if' scenarios. CEP for holistic value chain will not only increase business and process-level intelligence across all tiers of an enterprise resulting in faster reaction time to shop floor alerts or changing logistics situations but will also enable decision-makers to monitor 'exceptions' across geographically distributed plants. Furthermore, this research priority will open up business opportunities for SMEs to configure and sell analytics services on large enterprise data through the manufacturing app store.

7.4.6 Collaborative demand and supply planning, traceability, and execution

There is need in the future to enable manufacturing enterprises collaborating in global supply networks to cope with variable demands and highly complex products. These enterprises have to respond faster to demand and supply fluctuations and increase forecasting capability on the one hand and reduce cycle time and supply chain costs on the other. Network traceability would facilitate improved product genealogy and better identification of products for recalls and withdrawals. Furthermore, supply network planning and execution would lead to the assessment of supplier performance and identification of bottlenecks in the networks. The cloud middleware (facilitated by the MBW in Research Priority 7.4.1) provides an ideal information-sharing platform for performing planning, traceability, and execution in supply networks. To assist in making business decisions, research should correlate production KPIs and logistics KPIs for collaborative demand and supply optimisation and analyse cost implications for changes, exceptions, and bottlenecks. Mobile apps that bring manufacturing, sales, and logistics information under one roof for better planning and optimisation across supply networks should be developed and made available to stakeholders.

7.4.7 Digital rights management (DRM) of products and code in enterprise supply networks

Although strict laws for intellectual property rights (IPR) are commonplace, enforcement seems to be an issue in the absence of well-established ICT mechanisms for piracy detection and tracking. To counter the threat of piracy and counterfeiting of products, ICT research should apply and advance the latest advances made in digital rights management (DRM) for music, video, photographic images, and software to products that are manufactured in Europe and the software code embedded therein. DRM would also be crucial for ensuring the security and privacy of manufacturing apps available for download through the manufacturing app store. Security models for detecting piracy and tampering in products as well as embedded software/firmware within the product should be developed. Advanced protection techniques such as code obfuscation, watermarking, and digitally signed physical certificate of authentication (COA) should be investigated as part of future research. DRM research for manufacturing enterprises would not only mitigate the need to frequently change product designs to negate the effect of piracy and reverse engineering but will also instil confidence amongst customers of the 'Made in the EU' brand. Furthermore, the combination of DRM with RFID systems for storing information about the part along the production chain) would minimise also the number of scraps and re-works during the production processes.

7.4.8 Multi-enterprise role-based access control (MRBAC) in manufacturing enterprises

One of the greatest obstacles in the acceptance and adoption of cloud platforms in productive environments is the inability to manage and prevent threats originating from unauthorised access of enterprise data. For future manufacturing enterprises to effectively cooperate and collaborate in ecosystems comprising trusted as well as untrusted vendors, it is important that the notion of RBAC be extended and successfully applied in the context of manufacturing supply networks. Future research should focus on the ability to model trust and privacy requirements in multi-stakeholder supply networks joining data and services of enterprises. Development of security engines that are able to enforce security rules expressed in terms of roles and permissions on shared data and services during runtime and formal specifications of role hierarchies between actors of multiple enterprises perform separation of duties, and express constraints are required. This research priority is a necessity for encouraging more collaboration and trusted data sharing within enterprises supply network. Furthermore, audit trails for tracking and verifying repudiation claims between enterprises operating with shared data could be enforced for making manufacturing value chains more accountable and resilient.

7.5 Domain 5: Human-centred manufacturing

The set of research priorities in this domain focuses on enhancing the role and utilising the potential of people working in factories.

‘Human-centricity’ will be needed in factories of the future in order to increase flexibility, agility, and competitiveness. Factory workers (future ‘knowledge-workers’) will be given increased opportunities for continuous development of their skills and competencies through novel knowledge and capturing delivery mechanisms. Future enterprises will be better equipped for transferring skills to new generations of workers, and also proficient in assisting ageing, disabled and multi-cultural workers with better information and communication technology. Future manufacturing enterprises will use interactive e-learning tools to facilitate students’, apprentices’, and new workers’ gain in understanding of advanced manufacturing operations, also involving the use of new ICT paradigms.

Future knowledge-workers will use multi-modal UIs, intuitive and user-experience driven workflows, to safely plan, programme, operate, and maintain manufacturing systems. Mobile and ubiquitous ICT will allow workers to remotely control and supervise manufacturing operations. New safety systems will allow full adaptation of worker-robot collaboration that will enhance competitiveness and compensate for age- or inexperience-related worker limitations. Dynamic reallocation of tasks and changes in automation levels will enable human-automation symbiosis and full deployment of the skills of the European workforce. Enhancement and support of the workers’ cognitive skills will become increasingly important to create human-centred workplaces.

Three main aspects need to be considered, to understand and manage the roles and workplaces of people in the factories of the future:

- How people work and learn;
- How people interact with technology;
- How people add value to manufacturing.

At the core of future manufacturing is the information generated in the factory environment, which needs to be managed and adequately transformed from the data level to the knowledge level. The information must be appropriately understood and utilised by knowledge-workers and stakeholders, at all levels, in the manufacturing and business processes of the manufacturing value chain. Within this context efficient learning processes are also required. Ways to define simple work processes and principles, which empower the knowledge-worker and promote his/her 'heart and brain' also need to be further investigated.

7.5.1 New manufacturing education methods and e-learning

Innovative education methods and systems should be developed in manufacturing, with the ability to support the advanced long-life training of skilled workers, for an efficient take-up of new manufacturing knowledge, the safety at work and the active engagement of ageing or disabled workers. They should exploit advanced human-computer interfaces and innovative technologies such as immersive virtual reality, semantics-enhanced simulation, and web-based collaborative environments and integrated e-learning.

Methods for embedding e-learning tools in real-world situations need to be investigated. System interoperability and standardised interfaces are required to integrate e-learning tools with real life manufacturing processes and systems in the backend. Integration of e-learning tools with competence management systems and web-services also needs to be addressed. Future approaches should exploit and build upon emerging learning/training concepts and enabling environments for 'learning by doing', such as the 'teaching factory'. New person-to-person communication models and ICT frameworks for realising an efficient two-way knowledge communication channel between the factory (real-life manufacturing) and the academic/research site need to be further investigated within this context.

7.5.2 Advanced information models for knowledge creation and learning

The copious amounts of data in manufacturing environments can be used for knowledge creation and learning by workers in the factories through proper use of information models and archiving mechanisms. Best practices need to be captured and transformed into knowledge for later use. Facilitating the transfer of knowledge from skilled workers (e.g. older workers) to young or less experienced workers is of major importance for manufacturing enterprises. Therefore, advanced information models are needed to facilitate the transformation of data, information, events and decisions into a contextual-based environment. ICT training tools are further needed to improve the transfer of best practices to workers at the shop floor (e.g. to improve efficiency, productivity and reliability, or to prevent job risks). Such models and tools will support knowledge creation and learning at all levels (strategic, tactic, operation) for the entire product and factory life cycle. Future ICT research should focus on context-aware information modelling on data captured from the shop floor and enterprise backend systems. Semantic models for knowledge asset management and tools for natural language and gesture-detection and analysis should be developed. Lastly, ICT support for the creation of multi-media technical documentation to support exchanges between OEMs and service providers is needed.

7.5.3 Levels of automation and continuous adaptation of workplaces

Competitive manufacturing systems rely on humans and automation to jointly achieve manufacturing objectives. Traditional and static approaches to manufacturing system design and operation will be insufficient and must be replaced by adaptive and dynamically changing systems. Manufacturing tasks should be optimally allocated between humans and automation at any point in time where the human or the machine can perform the task better. Physical or mechanical automation levels are already high and increased cognitive automation (automated decision-making) levels can be achieved by advanced ICT. High variability, customisation pressure and extremely delicate supply chains also call for human-centred automation. There is a need to develop automation around human operators to leverage the human cognitive capabilities with advanced sensors and precision tools. Research should be focused on how to achieve and use the correct level of automation to be flexible, agile and competitive in manufacturing customised products for a global market.

Dynamically changing systems can also adapt and accommodate many worker limitations that are due to age, inexperience, inappropriate skill, or insufficient language skills. Relevant research should aim at methods and tools for a continuous adaptation of workplaces to the physical, sensorial and cognitive capabilities of workers, especially for older and disabled people, taking under consideration also the respective criteria and requirements of 'safety and health at work'. This will include requirements originating from the demographic change. The future approaches should consider the need to engage the workers themselves in the design and adaptation of the workplaces to ensure that they become attractive and inspiring for their users. Methods and tools should be exploiting technologies such as VR/AR and digital mannequins to support multi-criteria-based process and layout simulations and decision-making, on the basis of worker capabilities. Industrial social networking tools with rich user experience would be of great use to workers who work with machines and software systems simultaneously. Semantic technologies, digital libraries and intelligent information retrieval for manufacturing knowledge capitalisation from different interconnected (legacy) systems should furthermore be investigated.

7.5.4 New ways of interaction and collaboration between workers and other resources in manufacturing systems

Increasing complexity of manufacturing systems and processes creates the need for knowledge-workers to be supported by appropriate tools providing them with assistance for operations along the entire production chain in factories and further development of their competences. There is a clear need to contextualise from complex documentation. Appropriate interfaces (e.g. visual, audio, etc.) and assistance tools for knowledge communication will assist workers while performing manufacturing operations, including assembly, operation of machines, maintenance activities, ramp-up procedures, troubleshooting and remote guidance. Advanced human-machine interfaces for workers are required, considering:

- (i) usability and the related learning process;
- (ii) physical, sensorial and cognitive interaction; and
- (iii) fulfilment of safety and health conditions during human-machine interaction.

The expected, extensive collaboration between future knowledge-workers and robots (as well as other advanced automation equipment) will be crucial for successful human-centred

manufacturing. In this context, approaches to cooperative (human–robot) problem-solving need to be explored. It further requires research on safety, automation-level optimisation, ICT-based trust and communication optimisation, new human- and robot-based sensor packages, and new human/robot dialogue-based ways of automation programming.

7.5.5 New recommendation systems for the European workforce

As the methods for transformation of raw data into knowledge advance, it is becoming obvious that this increasing amount of extracted knowledge needs to be exploited in the most efficient manner. Soon, the amount of digital knowledge about manufacturing processes will exceed the human ability to process and utilise it. One of the directions for overcoming this problem is the development of the next generation of recommendation systems. Next generation needs to be such that it will not only be able to answer user questions, but will also be able to estimate the relevance of gained knowledge and report it to the user at the appropriate moment. The use of IoT to capture worker interactions with machines, business systems, and workflows should be leveraged in the future. Furthermore, research into well-structured knowledge warehouses, which are automatically populated, based on workers' interactions with the environment and business intelligence techniques to semantically annotate captured data in warehouse and business queries to extract relevant information on request should be invested in the future. Easy to use UIs to render recommendation information in platform-agnostic fashion on workstations as well as mobile devices of factory workers should complement the algorithmic and functional developments in the backend.

7.5.6 'Plug-and-play' interfaces for factory workers in dynamic work environments

European workers are finding it difficult to negotiate challenges in constrained environments where obstacles and hazards are commonplace. Challenges could be present in operations that require the usage of thick gloves for heat protection as well as in repetitive workflows that require quality check marking, for instance. In all cases, ICT has an important role to play by assisting workers to interact easily with the backend systems through easy-to-use intuitive interfaces. ICT for manufacturing research should focus on innovative mechanisms for easy interaction by leveraging the advances in HCI, motion sensing, computer vision, mobile interfaces, and design thinking. Motion sensing and gaming interfaces can significantly improve workers' interaction with factory machinery and enterprise systems, also taking into consideration criteria and knowledge of safety and health at work. UIs having 'plug-and-play' features (such as software libraries) that can be easily 'attached' to backend enterprise or manufacturing systems will furthermore make manufacturing software more flexible and easier to use.

7.5.7 Future tools for human activity monitoring and analysis

The complexity of processes in manufacturing requires optimisation at different levels. Optimising processes and workflows at the micro level through observation of the human workers themselves opens up a new area of research in ICT for manufacturing which assists workers in taking their own decisions. However, development of adaptive interfaces and emotion/mode-detection sensors will be necessary to enable unobtrusive and integrity-protecting monitoring of the human workforce. Appropriate tools and mechanisms are therefore required



in order to enable observation, indicators implementation, dashboards customisation and workflows optimisation, through simple and intuitive user-friendly UIs.

ICT monitoring tools should include criteria and knowledge of safety and health at work (processes, tasks or equipment). Modelling and representation of human behaviour in terms of intention, reaction, stress, strain, difficulties, and uncertainty is important. ICT middleware and analysis of observation sources, such as human-machine interaction event tracking, workflow tracking, and human-computer interaction through information modelling techniques should be researched. Future ICT research should furthermore develop dynamics dashboards with state-of-the-art UI libraries and mobile interfaces for workers to use seamlessly.

7.5.8 Enhanced visualisation of complex manufacturing and production data

As data volumes on the shop floor and plant levels continue to increase and manufacturing systems become more integrated, maintaining situation awareness, coping with information overload and improving the usability of complex technical or mathematical models pose a serious challenge. Future ICT solutions should focus on novel visualisation techniques that will abstract relevant data from real-world resources and business systems and display relevant information to knowledge-workers and decision-makers. Aspects of data mining and data management have to be considered in the context of this process. These data visualisation systems should be role-based, maintaining a level of abstraction and anonymisation based on viewer access levels. Ways to extract information from data dependent of user context need to be investigated. Future ICT research is needed to reduce the complexity of high-volume data through appropriate data clustering. Holistic approaches for visualisation of multi-scale models and simulation results of manufacturing systems for better understanding by humans should be developed. Furthermore, new UI standards such as HTML5, next generation graphics rendering algorithms, and mobile apps for workers that use the data-push mechanism to display KPIs and exception conditions should be developed.

7.5.9 Linking organisational knowledge in connected enterprises

Extended enterprises are a reality and the notion is a strongly encouraged vision of ‘virtual factories’. In addition to tackling information-sharing issues between machines and systems of these extended enterprises, we also have to address the ‘human mobility’ trend whereby highly skilled people from one organisation move to another, bringing invaluable know-how with them. Even within the same organisation, human resources move from one installation to another that might be dispersed across countries and continents. New ICT methods can be exploited to link people and make their expertise explicit to each other. Future research should focus on context-aware information modelling on data captured at the enterprise and human-machine interaction levels. Captured data should be exposed via controlled social networking tools and private enterprise clouds in order to connect human implicit knowledge with factory and production knowledge. Additionally, novel semantic technologies for annotating and referencing knowledge and identifier resolution schemes to identify correct and relevant knowledge and mapping against human stakeholder(s) should be developed.

7.5.10 New ICT-facilitated initiatives to make manufacturing more attractive for younger and older generations

Manufacturing, as a prospective career option, is not considered an attractive enough field by a significant percentage of the young talent pool in Europe. This is posing a serious threat to the competitiveness of European factories of the future. Lack of new talent would result in stagnation of innovation, pressure on the ageing population and heavy fiscal losses to enterprises. ICT can play a pivotal role in making manufacturing more attractive through the development of tools and methodologies, such as serious games, demonstrators and social networks that engage the potential workforce from an early stage. Procedures to identify and reinforce the capacity of workers to remain motivated during their working day need also to be investigated. Furthermore, ICT could give more engagement opportunities such as product design and app development to the younger generation who are already technology savvy and adept at problem solving through programming in the mobile environment. Future ICT research should develop metrics and feedback mechanisms to understand the impact on younger generations. Furthermore, APIs that engage younger generations of ICT programmers into service and app development for manufacturing enterprises should be developed and made easily available in the academia.

7.5.11 Demonstrating smart factories that attract people

In the future, manufacturing enterprises will offer their jobs on the labour market and seek means to be attractive to their (potential) workers. This involves questions like how to schedule work in ways not thought to be possible today and how to design workplaces so that they are attractive to people. On many levels people will have to change their views, their ways of working and interaction and their way of living if they want to adapt successfully to the global challenges.

The aim of this research priority is to demonstrate the operation of a smart factory, in which all workers are recognised individually. Image processing will allow for ‘knowing and recognising in the background’ their gestures, their interaction among each other and provide them with on-the-spot knowledge that they need for their respective tasks. Interactive displays and defined gestures allow for quickly triggering machine-man interaction. Not only the worker

will be reminded of fulfilling a specific task but also a manager's decision based on a wrong assumption can be quickly corrected, made known to his colleagues or environment and thus lead to more open interoperability.

This research priority addresses work organisation in direct and indirect production departments, human-machine interaction on all levels and factors improving and making better use of the huge potential of qualities of human beings. This will lead to a new look at the people in the production systems and it will inevitably address the field of what is a system architecture supporting such interactions. Attractive research will support manufacturing enterprises in Europe in their respective efforts for talents to be employed in attractive manufacturing jobs.

7.6 Domain 6: Customer-focused manufacturing

The set of research priorities under this domain focuses on involving customers in the manufacturing value chain, from product-process design to manufacturing-associated innovative services.

Previously considered solely as a 'marketing target', the customer in recent years has earned a special status in the space of future manufacturing enterprises. He/she is more informed, demanding, and does not hesitate to use all technological means at his/her disposal to make his/her voice and needs heard. Nowadays, customers are best placed to assess and influence product development across different functional units of manufacturing enterprises. If the end product (in its extended meaning, considering also the related services) meets customers' requirements and expectations, it has every chance of making an impact in the market. Manufacturing enterprises that design and develop products without involving customers in the loop are likely to end up with commercially unsuccessful products. User-centred design (UCD) requires that product development should be user-led rather than by technologists and developers.

The integration of the customer will be through the identification of requirements and interpretations during the design phase. Future manufacturing enterprises would collect explicit as well as tacit customer requirements, analyse them and make the right product and service model. It would extract customer feedback from all possible sources, including real-time product usage, social media and incorporate it into engineering and manufacturing processes. Furthermore, enterprises are also expected to offer a comprehensive range of after-sales product services once the customer has bought a product.

Taking the environment into account has also become a prerequisite in product development. Designers use different ICT tools at different levels in order to come up with 'eco-designed' products. 'Eco-design' puts the spotlight on an earlier phase within the value-added chain: especially the phase of customer requirements. It focuses on the links between the business, customers, and the environment, in formulating a requirements specification by incorporating both the 'voice of the customer' and the 'voice of the environment'.

Sustainability on a social, environmental and economic level is strongly dependent on the availability of information about the product throughout its life cycle. Future manufacturing enterprises will be able to attain the quality-price-personalisation-sustainability trade-off by intelligent product design through customer collaboration as well as through state-of-the-art approaches such as design thinking, and new approaches to synchronise different design/eco-design stages.

Approaches and tools to assess the impact and costs of early design decisions throughout the whole product life cycle including the production, the utilisation (with all the related service activities) till the de-production and end-of-life stages have to be developed to provide designers with a holistic view of the product/service impact.

7.6.1 Manufacturing intelligence for informed product design

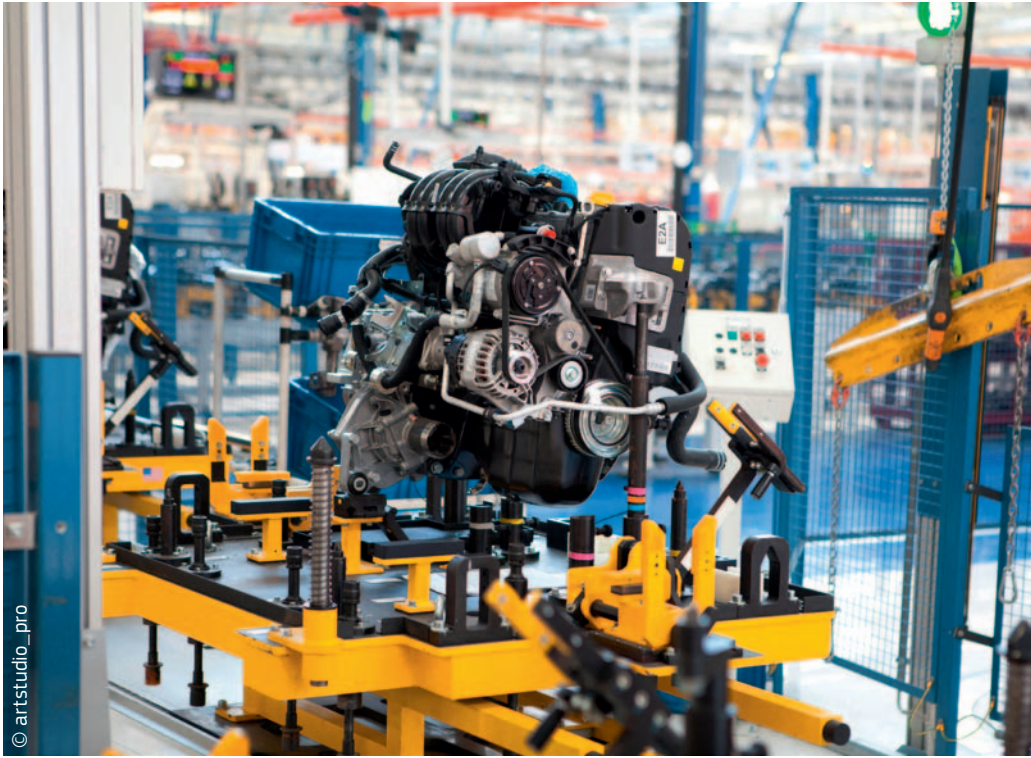
In order to cope with global competition, companies are increasing the number of new product introductions (NPIs) in the market and consequently shortening the life cycle of the product itself. To fulfil this trend, time-to-market (T2M) is decreasing and designers are pressured to accelerate the product design phase and use more expertise from manufacturing phases. A more frequent feedback loop without media breaks between product engineering and the manufacturing and assembly phases is required to ensure high quality products at low production costs. ICT for manufacturing intelligence should enable the integration between engineering and manufacturing phases of products by integrating CAD, CAM and PDM/PLM tools. Shared and secure (digital rights management) middleware, leveraging cloud-offerings in the future, for exchanging manufacturing data in the design network and giving knowledge about quality and productivity issues are also important research directions in the future. Furthermore, effective implementation should be done to extend PLM tools with bi-directional alerting (from designer to manufacturer and vice versa) and faster search functionalities for reusable designs.

7.6.2 ICT Solutions for energy-efficient product life cycles and ECO-usage

Research is needed in new software solutions to monitor and improve energy efficiency of products throughout their usage by customers by leveraging new enabling technologies such as smart embedded systems, IoT, low-powered sensors, and M2M integration in manufacturing and maintenance. Integrated data collection about energy consumption at each step of the life cycle and analysis (e.g. autonomous, small, robust, smart embedded devices) through advances in IoT should be explored. Data collected in real-time will allow the creation of detailed virtual models of product energy consumption thus going beyond traditional LCA and LCC approaches. The innovation should focus on encompassing whole product life cycles as well as specific life cycle phases. Future ICT research should also focus on multi-criteria analysis and optimisation based on new standardised virtual model and eco-design-related KPIs within the product life cycle simulation tools. New visualisation techniques based on innovative UIs and apps for displaying KPIs on product energy consumption to manufacturers and customers should furthermore be enhanced to complement the backend tools.

7.6.3 Collaborative product-service systems design environments for SME involvement

Enterprises are increasingly facing complexity resulting from frequently changing designs and therefore need to collaborate as a single virtual organisation to keep track of the requirements of product-service systems. This research priority focuses on increasing reactivity to demand and rapidly delivering new products leveraging business relationships and local expertise with focus on SME participation. Future ICT research needs to leverage the cloud-computing paradigm as the basis for communication amongst human stakeholders (designers as well as customers) for exchanging data and information (e.g. API, data standards). Interoperable and



open interfaces to connect to systems across geographically dispersed competence centres, in particular those used by SMEs and digital rights management (DRM) to protect intellectual property (especially for jointly created product designs with SMEs) are needed. Agile UIs and mobile apps for seamless collaboration by designers and customers without requiring complex configurations will complement the functional aspects with usability properties.

7.6.4 Crowd sourcing for highly personalised and innovative product design

The Web 2.0 paradigm has brought about the emergence of social networks through which a sizeable number of the world's population is now connected. Future manufacturing will depend on the seamless conversion of the customer-specific requirements (personalisation) and collective requirements (human-centred) into a single and successful product opportunity. However, the languages for expressing customer-specific requirements and product manufacturing collaboration capabilities are divergent in syntax. There is a need for specialised social networks that can source new implicit expectations and user information (anthropometric data, physical capacities, emotions, preferences, etc.) and convert them into innovative functional requirements for personalised solution design. Semantic technologies for collecting, understanding, and analysing customer expectations through social networks and HMI technologies (e.g. visual, language-independent 3D model for customer's product interaction, 3D simulation and comparison between models proposed by different designers, opinion and sentiment analysis using text mining, emotional recognition) should be explored. Furthermore, easy-to-configure and enterprise-specific public/private social networks should be developed to engage and encourage customer involvement in product design and feedback. Finally, learning and competence build-up should be considered as well as protection and management of intellectual property rights.

7.6.5 Product-service simulation for sustainability impact

While designing or improving a new product or service, many possible scenarios need to be explored ranging from the choice of specifications, design, materials, 'make or buy' and suppliers, to manufacturing strategy (produce to order or make to stock), product usage (profiles of customers), product servitisation (type of maintenance services proposed), and eventually product recycling/reuse. Considering the increase of mass customised product-services, this scenario analysis will become a key strategic selling tool. This research priority aims at developing a framework for life cycle simulation and for digital mock-ups of product and services in their environment in order to optimise product and services value as well as impact from a financial, environmental and social point of view. Simulation tools and digital mock-ups for product servitisation and recycling, assessing its value and impact for stakeholders should be developed.

In future algorithmic 'what if' analysis, leveraging visualisation techniques and multi-criteria optimisation using mock-ups as well as the power of cloud computing's IaaS ability to perform outsource simulation and analytics (especially for SMEs,) should be explored.

7.6.6 Costing and manufacturability assessment

New products designers and programme managers must be able to make fast decisions regarding parts and material sourcing, detailed product design, and internal manufacturing capabilities. Therefore, predictive models of costs and technical capabilities are required covering both the internal manufacturing organisation and the supply network. This will enable future manufacturing enterprises to not only capture the correct market demand and manufacturing feasibility for new products, but also prepare a competitive pricing model for its new products based on customer distribution and product uptake. Future research for realising this research priority should look into predictive costing models capable of generating detailed business estimates based on product design, market-demand scenarios and possible manufacturing strategies. Searchable ontologies for mapping company experience, expertise and capability to deliver products according to new designs and research in correlated financial and manufacturability KPIs to capture business and market relevance based on product uptake are possible ways forward.

7.6.7 Data collection, analysis and anonymisation during product usage

Future manufacturing enterprises will not only be able to improve the design and functionality of their products but will also be able to lower energy and resource consumption if they are able to monitor how customers use their products. The usage feedback from customers may also assist the manufacturer in customising a particular product based on classification of its customer base and service sectors. However, monitoring product usage during its operational life cycle is not a trivial task, as it requires: (a) large-scale data collection, processing, and visualisation; and (b) guaranteeing privacy of the customer and their product usage patterns through anonymisation. Research should focus on using advanced sensors and the IoT to transfer product-specific data to monitoring logic hosted in cloud infrastructure. Development of usage mark-up language to easily decipher and consume usage patterns of products and of data anonymisation techniques such as obfuscation, randomisation, reduction, and perturbation to disassociate customer information from collected data should be investigated.

7.6.8 Mobile servicing cockpit for extended business offerings

The domain of product after-sales services is a lucrative business proposition to manufacturing enterprises in Europe. Not only does it enable manufacturers to earn revenue by serving their customers but also the customers reap benefit by accessing a 'one stop shop' for servicing their products and buying supplementary services offered with them. Through future research in mobile maintenance and servicing cockpit, manufactures and customers (both B2B and B2C) will be able to offer and consume the entire spectrum of product after-sales services under one roof via the mobile infrastructure and store in the cloud. Future research should use advances in IoT and product traceability to devise identifiers to map unique product IDs to corresponding service offerings, develop transactional models for customers to purchase and consume after-sales services, and add semantic search functionality to correlate product, after-sales services to third party added-value services. The mobile servicing cockpit should be integrated with backend enterprise systems for inventory and asset tracking and offer intuitive mobile UIs for customers to visualise and browse the entire range of available service offerings for products.

7.6.9 On-demand manufacturing of customer-centred products

Today's markets ask for flexible on-demand capacities. The Internet economy and individualisation needs are pushing, in particular, for fast product/service systems able to combine rapid and flexible production capabilities with enhanced product design capabilities and exploit minimal distribution lead-times to match supply with volatile demand. From a technological point of view demand-driven manufacturing involves a synchronised, closed loop between customer orders, production scheduling, and manufacturing execution; all while simultaneously coordinating the flow of materials and information along the supply chain. Research must aim at a more coordinated and fast interaction between different tools and technologies serving product life cycle in order to go beyond common 'one-stage' acceleration and by reducing their production lead times by operating in a variable supply network.

Design tools should identify and transfer key consumer requirements and collected data from suppliers into automated process routines. Manufacturing processes should flexibly integrate design specifications into efficient operational routines by keeping a comparable throughput time in different configurations. In particular, manufacturers must enforce and electronically document product quality throughout the production process. Supply chain networks should assure strict coordination action with production routines; finally, enterprise resource planning (ERP), manufacturing execution systems (MES), and the supply chain by layering advanced planning and scheduling (APS) and lean manufacturing should be integrated to synchronise production with demand while streamlining material-flow. This requires particularly robust 'built-to-order' models for production design, planning and control-on-demand manufacturing of individualised products.

7.6.10 Customer-focused products quality assessment standards and tools

Virtual information related to product features is essential in determining the products' added value. New standards can provide data and quality assurance which can be managed in supply networks providing high quality products. In particular new paradigms like product individualisation and mass customisation call for new standard systems in order to fully implement the benefits of standardisation and scale economies. Partner manufacturing firms are asked not

only to operate in compliance with all applicable legal requirements (business conduct, product quality, labour and employment practices, health and safety and environmental protection) but also to meet quality requirements in order to provide goods and services that consistently meet standard specifications and customers' needs, for performance, well-being, health and safety. A proper multi-set of fixed data which are equally recognised by the different stakeholders can facilitate supply network management, manufacturing control and customer decision. Such research aims to produce new, fast and reliable standardisation data systems enclosing multiple sources of specifications to provide maximal information and value along the product chain. In order to reduce standardisation costs new functional standards and management approaches should maximise outcomes due to their use, to reduce conformity checks, to promote automated checking, to accelerate manufacture processes and product-data collection.

7.6.11 Manufacturing solutions for modular, updatable, reconfigurable and disassemblable products

New products will be more and more incorporating of inter-connectable intelligence and smart functionalities through advanced materials and components. At the same time the integration of highly differentiated components and embedded intelligence are key requisites for flexible manufacturing of strongly customer-focused products with a wider range of high value adding customisation options. On the other hand increased integration of sophisticated functional and ICT-based components can imply a faster product obsolescence rate such as experienced today with certain consumer electronic products and can introduce further waste generation problems or pollution risks. In order to face such new challenges new manufacturing techniques should enable, in parallel, the fast customisation, assembly and manufacturing of complex products and their spare parts as well as fast and effective product updatability, reconfigurability and disassembly by the original manufacturer, the end-user or specialised service providers. The integration of sub-elements, in particular, which can be independently created, integrated/disintegrated and used in different product systems requires specific R & D efforts oriented to transparency of industry standards for key interfaces, to advanced assembly technologies and advanced CAD and MES instruments for complex modular products design and production, as well as for their update and partial or total disassembly, recycling or reuse.

7.6.12 Implementation of creativity and user-driven innovation through flexible design and manufacturing processes

A key challenge related to customer-centred product design is the rapid change in volatile end-market demand based on fast-changing market trends and needs. Main success drivers can be constant non-technological innovation through design/creativity, novel modifications introduced by users and a quick response to demand changes. The application of such factors within product engineering requires a quality compliant with consumer expectation and additional flexibility to continuously modify products without drastic redesign of core-product base and operations. From a manufacturing perspective this requires pervasive integration of ICT design technologies providing an improved degree of options together with flexible production technologies.

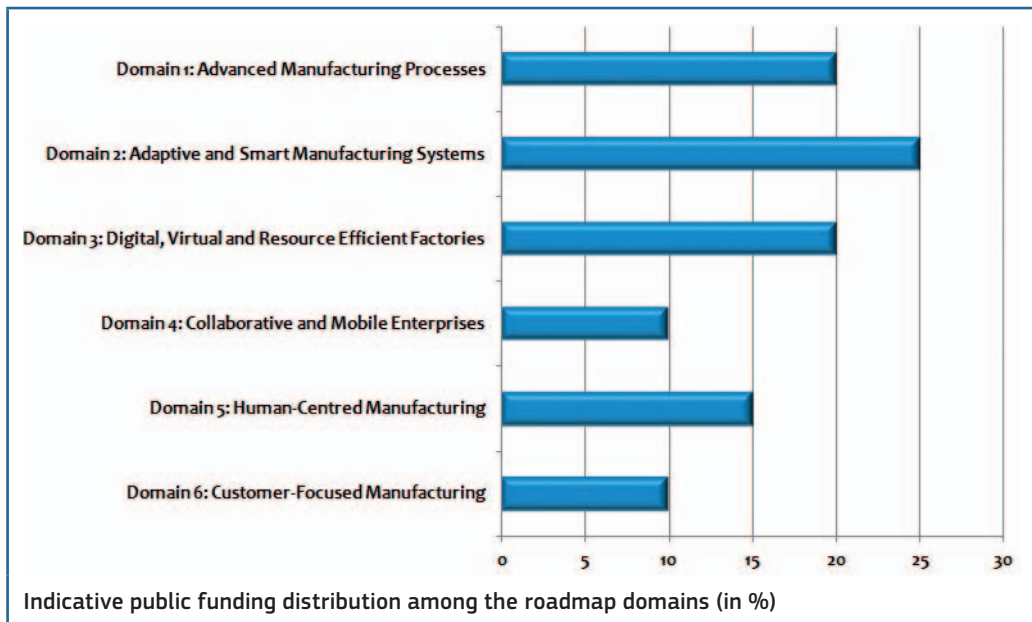
Potential creativity should be exploited through the improvement of mediated communication (e.g. via websites or via social media) with end-users and their role in the creation/production or selling processes (via digital means). From a design perspective new disciplinary areas like emotional engineering or co-design tools can lead to research on integration between new

data management systems and traditional CAD tools. From a manufacturing perspective the use of additive/subtractive technologies, multifunctional machines, flexible joining technologies, provides the basis for the new required variability. Such technologies can decrease the time-to-market for new creative products as well as their life cycle costs by realising finished parts directly from digital inputs. Novel simulation and fast testing methodologies are also required to assure that properties of such innovative products are compliant with common product quality requirements (i.e. reliability, safety, environmental-friendliness, etc).

8 Proposed funding distribution

The realisation of the research and innovation objectives of the Factories of the Future PPP will require a public funding budget of EUR 500 million/year which the private sector is committed to match with equivalent contribution in kind. The overall resulting size of the Factories of the Future programme within Horizon 2020 will then become EUR 7 billion.

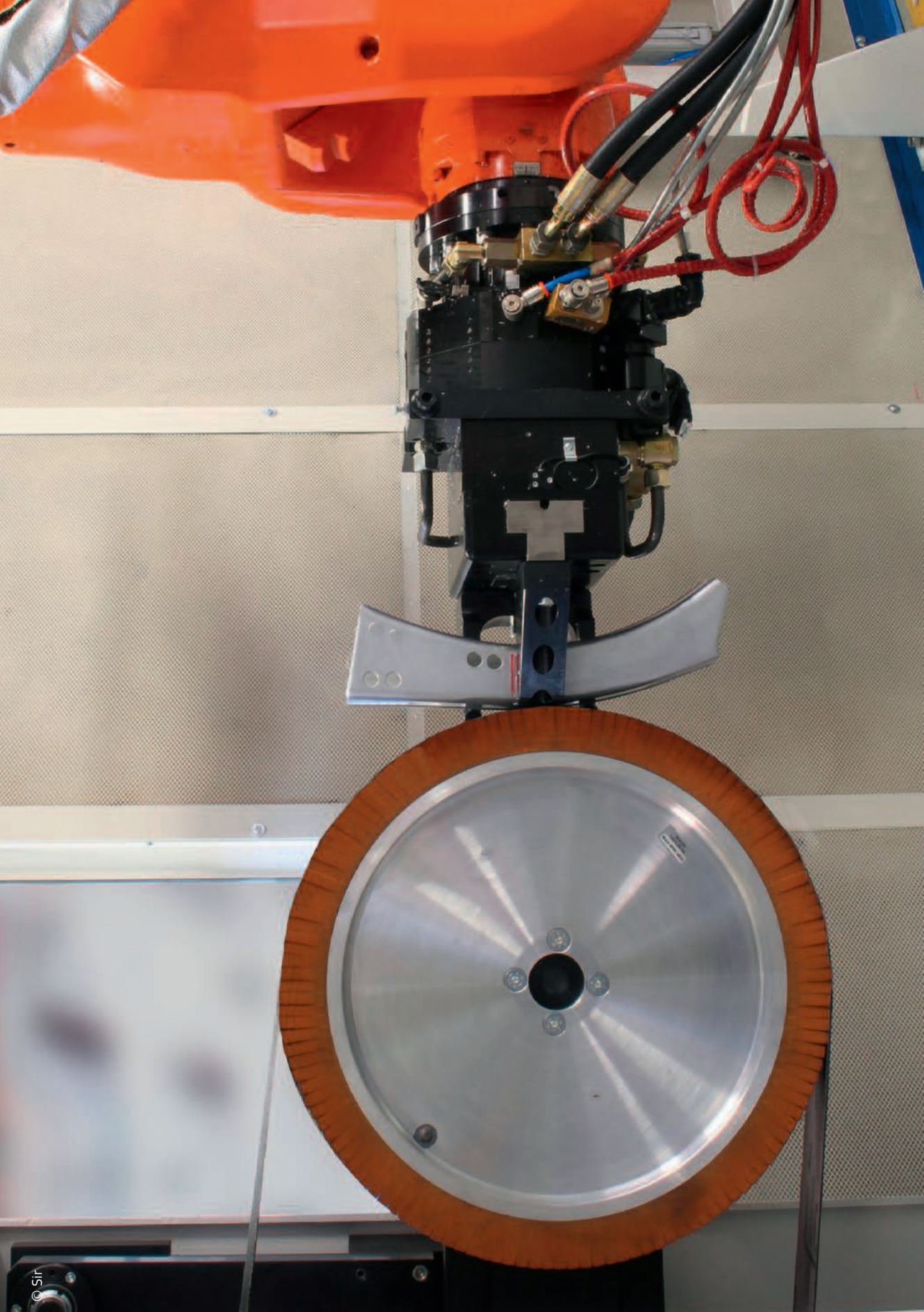
An indicative proposed public funding distribution among the roadmap domains is shown in the table below. These figures take into account the substantial budgets that are required to implement demonstrators and pilot applications or production facilities. It is anticipated that up to 40 % of the budget will be dedicated to demonstration activities.



The table below lists the research priorities (listed per domain) that should preferably be addressed during the first 2 years (or first two calls for proposals) of the FoF PPP. This is based on the maturity of the proposed solutions, considering also the progress of the Factories of the Future projects started under the FP7 programme. It also takes into account a prioritisation exercise that was carried out during the public consultations.

Reference	Research priority title
7.1.2	Advanced joining and assembly technologies for advanced and multi-materials
7.1.1	Manufacturing for custom-made parts.
7.1.6	Material-efficient manufacturing processes
7.1.9	Integrated manufacturing processes
7.1.11	Product life cycle management for advanced materials
7.1.5	Delivery of new functionalities through (mass production) surface manufacturing processes
7.1.3	Automated production of thermoset, and ceramic thermoplastic composite structures/products
7.2.1	Flexible and reconfigurable machinery and robots
7.2.3	Symbiotic safe and productive human–robot interaction, professional service robots and multimodal human–machine–robot collaboration in manufacturing
7.2.13	M2M cloud connectivity for future manufacturing enterprises
7.2.7	Micro-precision into micro- and macro-production equipment
7.2.12	Monitoring, perception and awareness on manufacturing
7.2.2	Embedded cognitive functions for supporting the use of machinery and robot systems in changing shop floor environments
7.2.11	Dynamic manufacturing execution environments for their smarter integration into dynamic and agile shop floors
7.2.5	Mechatronics and new machine architectures for adaptive and evolving factories
7.2.4	Smart robotics — scaling up for flexible production and manufacturing
7.2.14	Intuitive interfaces, mobility and rich user experience at the shop floor

Reference	Research priority title
7.2.10	Adaptive process automation and control for a sensing shop floor
7.3.4	Energy monitoring and energy management in future manufacturing enterprises
7.3.2	Intelligent maintenance systems for increased reliability of production systems
7.3.9	System-oriented quality control strategies in multi-stage manufacturing
7.3.10	Design and management of production machinery and processes
7.3.5	Multi-level simulation and analytics for improving production quality and throughput
7.3.13	Integration of design methods and tools
7.4.6	Collaborative demand and supply planning, traceability and execution
7.4.4	Connected objects for assets and enterprises in the supply networks
7.4.1	Cloud-based manufacturing business web for supply network collaboration
7.4.2	'End-of-life' (EoL) applications in a network of re-manufacturing stakeholders
7.5.4	New ways of interaction and collaboration between workers and other resources in manufacturing systems
7.5.11	Demonstrating smart factories that attract people
7.5.3	Levels of automation and continuous adaptation of workplaces
7.5.1	New manufacturing education methods and e-learning
7.6.1	Manufacturing intelligence for informed product design
7.6.2	ICT Solutions for energy-efficient product life cycles and ECO-usage
7.6.3	Collaborative product-service systems design environments for SME involvement



Part III: Expected impacts

9 Scale of the resources involved and ability to leverage additional investments in research and innovation

9.1 Innovation through dissemination and demonstration

R & D investments become economically and socially relevant when they generate value for companies and society via the creation and exploitation of new products, services, business models and processes, the development of new knowledge and skills as well as with the creation of new and better jobs. In the European Commission communication on industrial policy (entitled 'A stronger European Industry for Growth and Economic Recovery'), the EU's objectives are to reverse the decline of manufacturing's share of EU GDP and to increase it from 16 % to 20 % by 2020. These objectives are particularly relevant in an industry-led initiative such as the Factories of the Future PPP and when public funds are involved.

Going from research activities to commercial exploitation is a long, non-linear process that can be described in a simplified way using the technology readiness level (TRL) scheme. In the Factories of the Future programme the TRL scheme is **focused on manufacturing technology**, where TRL 4-7 involves the demonstration of the manufacturing system or manufacturing enabling technology:

Technology Readiness Level (TRL) of Manufacturing Technology								
1	2	3	4	5	6	7	8	9
Basic principles observed	Technology concept and/or application formulated	Analytical and experimental proof of concept	Technology validation in laboratory environment	Technology validation in relevant environment	System/subsystem model or prototype demonstration in a relevant environment	System prototype demonstration in an operational environment.	Actual system completed and qualified through test and demonstration	Actual system proven through successful operation.

Technology readiness level scheme

The implementation of an effective and efficient innovation process calls for a better and faster coverage of the entire cycle (from research to commercial exploitation or concepts–capabilities–cash (3C)). This can only be achieved if project consortia gather or have access to all the necessary resources (technologies, people, funding, etc.) and if the number of steps are minimised (more integrated projects, covering several levels).

It's also important to mention that, as projects move towards market application:

- competition increases (opportunities and areas for cooperative activities are reduced);
- funding needs increase significantly;
- the usage of public funding becomes more questionable and difficult to manage.

Until recently, typical EU R & D programmes covered a limited level of demonstration activities. With the demo-targeted projects, created in the scope of the Factories of the Future PPP, a major step was taken towards a better coverage of the innovation cycle, allowing the inclusion of other types of activities, like technology integration, and pushing for a higher level of dissemination and demonstration activities, including in industrial environments.

In addition to the recommended demo-targeted approach within the FoF PPP, the challenge for the next decade is to take this trend even further, creating the conditions for projects and consortia to bring their results to a pre-commercial/exploitation stage (TRL 8).

As was mentioned before, such a complementary programme will call for more complete consortia capable of gathering all the necessary resources and competences. The funding needs will also increase significantly and that, matched with the fact that final results (or, at least, some of them) will be more region-, sector- or company-specific, will require a new combination of different funding sources, both public and private and could include cohesion funds or risk capital to lower the financial risk.

It is also important to stress that, since the Factories of the Future PPP targets the development of horizontal and enabling technologies, research projects' results need to be disseminated across the entire industry in Europe, not only among the sectors and regions directly involved and, as a result, unleashing their full potential impact, by promoting their exploitation in other applications. Pilot lines that build on FoF projects should therefore strive for cross-sector impact and avoid distortion of competition. Existing cluster organisations and 'open innovation' concepts and tools can be used to support these objectives.

As previously mentioned, it becomes clear that dissemination and demonstration activities are critical for the successful exploitation of research and innovation projects' results. The

goal is to promote market awareness, understanding, support, involvement or action of the stakeholders regarding the technologies' developments, potential and subsequent application (products, services, processes, etc., see also section O).

Considering the specific scope of the Factories of the Future PPP, the two following complementary levels were defined:

Within the Factories of the Future PPP: Industrial lab

The industrial lab activity should present the technology in a 'controlled' environment, either in a university or research and technology organisation industrial lab, or in a factory lab. This aims at demonstrating the technology at an advanced development stage, with a certain degree of stability, and producing the required outputs, even if it is without the desired performance. The observation of the technology at this stage will raise awareness, create the confidence to accompany its later development phases and consider the technology as a future solution.

Complementing and building on Factories of the Future PPP results: Industrial pilot production

This level should present the technology in pilot production, embedded in a real environment, which aims at showing its whole capabilities. By observing and interacting with the technology at this stage, stakeholders will be able to understand and take decisions concerning its application.

These 'demonstration infrastructures' can also play a significant role as education and training environments, both for developers and users/customers, creating a framework for a better understanding of the technologies and their present and future applications. It is important that projects also include training (especially for young people) and other effective knowledge-transfer mechanisms.

Development of technology solutions will not always make it to industrial implementation, or not rapidly enough, without the understanding of the context within which the technology operates. This can include, for example, regulations, standards, barriers to adoption and just simply market awareness of the value the technology will deliver. Programmes will need to address how they will engage stakeholders and support new regulations and standards to accelerate adoption of the new manufacturing systems, and hence bring value back to the EU.

Research and innovation for the factories of the future is not only a matter of developing and integrating novel technologies. Manufacturing opportunities can only be properly addressed if the manufacturing community understands the mechanisms to create value. 'Thinking outside of the box' is not only required for generating technological innovation, it is also required for generating new approaches to operating supply chains and addressing markets.

Increasing competitiveness through the design of a new product requires the development of a company strategy where product and process innovation is seen as a permanent, widely distributed, multi-level, social-oriented and user-centred activity. User-driven innovation should therefore become a business model in itself and a continuously run business process ('the factory innovation'). But investments in research and innovation, both public and private, can only be sustainable if proved to generate competitive advantages, business value, economic and social development, etc. This calls for more effective ways of monitoring and evaluating projects and programmes results and impacts, especially after their financial execution.

9.2 Leveraging additional investment in research and innovation

The Factories of the Future PPP is also expected to attract additional funding for R & D activities. The strong industrial relevance of the PPP roadmap and the long-term commitment of key industrial players have led to an increasing interest from manufacturing industry in the partnership's research activities. This is expected to be confirmed as the PPP continues under Horizon 2020. This could gradually attract more R & D funding from the private sector. In addition, another relevant consideration is that input additionality is of interest when the industrial investment is in Europe. Industry R & D is increasingly global and companies locate their operations where they get the best conditions. Public financial aid, in the form of an efficient R & D programme with important networking effects, can be an important factor in determining a company's decision on where to spend its R & D money.

Additionality of funds may be also expected from the public sector, based on the potential for linkages and resource leverage between other national and European programmes. Coordination with ERA-NET, Eureka and Horizon 2020 is expected towards that direction. A promising relation between the Factories of the Future PPP and complementing regional funds is expected through the Smart Specialisation scheme.

Based upon these mechanisms and the long-term commitment of industry, it is expected that the Factories of the Future PPP will stimulate more private investment than a 'business-as-usual' approach of a public research programme. Since potential users and investors are involved in setting the programme focus, the project targets and the validation of results, the investment risk is mitigated, new business opportunities created and the attractiveness of further investments increases. Furthermore, a considerable acceleration of the innovation process and an earlier market success can be expected.

In the future, EFFRA will expand this approach for fostering the uptake and exploitation of the results, further enhancing the impact potential (clustering of projects, active transfer of results, community-building activities).

A smarter and more efficient use of public funding

As mentioned in section 9.1, the funding required to cover the entire innovation cycle will increase significantly and that, matched with the fact that final results (or at least some of them) will be more region-, sector- or company-specific, will require a new combination of different funding sources, both public and private, that could include cohesion funds, risk capital, etc.

The Manufuture national and regional technology platforms (NRTP) group has been working on these objectives for several years, promoting or supporting the creation or implementation of programmes, initiatives and projects, at a national/regional level, which are complementary and aligned with the European programmes. This is aiming at a better coverage of the innovation cycle. This includes 27 cluster initiatives and 40 research and innovation funding programmes, in some cases already using cohesion funds. Moreover several national industry associations are involved in the setting up of structural national initiatives, in some cases in national PPPs inspired by the European Factories of the Future PPP. The work at national level

is of utmost importance, since participation in EU research activities varies from country to country and from region to region.

In summary, throughout Europe there are national manufacturing initiatives under different names and brandings: some are called Manufuture NRTPs, others name themselves national Factories of the Future PPP, others Manu-initiative or similar. This existing work fits very well with the new European strategy called 'Smart Specialisation', which is the European Commission's strategic targeted approach to Structural Fund investments to boost regional research and innovation and strengthen economic development. The strategy works towards an increase of public funding for research and innovation projects and activities, developed at a regional level, and towards promoting a better alignment and coordination between the European and the national and regional policies and funding programmes. These objectives aim at allocating a significantly increased percentage of the cohesion funds for research and innovation supporting programmes, in areas defined by the national and regional authorities (depending on their specialisation and strategies) and aligned with the European priorities. To have access to these funds, regions need to propose national/regional competitiveness programmes, defining their priorities and presenting an action plan, with objectives, activities and expected results and impacts.

The manufacturing community is answering to the smart specialisation policy by working closely with the European and national and regional authorities, and also with the most relevant stakeholders at a national/regional level, i.e. cluster organisations. Work in this area is ongoing, for example a workshop co-organised by Manufuture/EFFRA, the JRC, DG Research and Innovation and DG Regional and Urban Policy entitled 'Unleashing the potential of advanced manufacturing technologies using smart specialisation' in March 2013. More events and meetings will follow at the Manufuture Conference in October 2013 and at the level of Orgalime. The aim of these activities is to ensure that manufacturing industry in general and production technologies/advanced manufacturing systems in particular are considered a strategic investment area and included in the different competitiveness programmes. It is also important to stress that transnational/regional strategies, meaning the agreement of several regions to work on specific areas/sectors/themes, are valued by the European Commission.

An example of the work already developed in this area is the Baltic Sea Region (BSR) Manufacturing Belt initiative, involving 11 countries/regions, 8 of them covered by Manufuture NRTPs. The BSR Manufacturing Belt promotes research and innovation strategies for smart specialisation, improving scientific and technological excellence and strengthening competitiveness and innovation in manufacturing all over the Baltic Sea Region countries, and attracting more private investments for research and innovation in the region. Stakeholders such as universities and higher education institutions, local industry, research and technology centres, development and innovation agencies, as well as social partners, are widely involved in the work. The BSR includes a combination of leading, high-tech and developing countries/regions, paving the way for knowledge and technology transfer and for building a 'staircase to excellence' in less advanced countries. The manufacturing industry is a significant employer in the region and its success has a great social influence.

Beside the smart specialisation policy, the manufacturing community is also preparing for the planned knowledge and innovation community (KIC) on added-value manufacturing, which will be launched by the European Innovation and Technology Institute (EIT) in the coming years. The EFFRA and Manufuture community shapes this discussion and has organised events on this subject, the biggest being a public event in the European Parliament in February 2013. A 'manufacturing KIC' is seen as opportunity to improve existing fragmented structures in Europe. The KIC would provide an institutional framework to link EU and national initiatives with each other and to allow a better cooperation between research, education and businesses. Members of the Manufuture/EFFRA community are involved in the project Know-Fact in cooperation with DG Education and Culture and in other skills-focused projects by DG Research and Innovation and DG Connect. Hence a possible framework for a manufacturing-KIC comprising these projects, the FoF PPP and national initiatives is already there.

The manufacturing community was also encouraged by the European Parliament and some Member States, who during the end-phase of the trialogue negotiations on Horizon 2020 decided to even advance the launch of the manufacturing-KIC, from 2018 to 2016.

Leveraging investments

Based upon these mechanisms and the long-term commitment of industry, it is expected that the Factories of the Future PPP will stimulate more private investment than a 'business-as-usual' approach of a public research programme.

Since potential users and investors are involved in setting the programme focus, the project targets and the validation of results, the investment risk is mitigated, new business opportunities created and the attractiveness of further investments increases. Furthermore, a considerable acceleration of the innovation process and an earlier market success can be expected.

In the future, EFFRA will expand this approach for fostering the uptake and exploitation of the results, further enhancing the impact potential (clustering of projects, active transfer of results, community-building activities). A leverage factor of investments for industrial deployment of 5 to 10 is expected.

10 Expected impacts on industry and society

In brief — and as already expressed in part I — the major expected impact includes the following components:

In general terms:

- Reach EU 2020 and Horizon 2020 targets, by addressing both societal challenges and industrial competitiveness:
 - Creating competitiveness and growth, sustainability and employment (inclusion);
 - Creating sustainable, safe and attractive workplaces;
 - Fostering the creation of technological-based companies around manufacturing of innovative products.
- Reach EU industrial policy targets:
 - Sustainable growth of EU manufacturing within a context of global competition, raising the share of manufacturing in EU GDP from 16 % to 20 % in 2020 ('EC industrial policy communication October 2012');
 - Increasing value added by manufacturing.
- Underpin EU trade and investment policy:
 - EU to remain the leading trade region in the world, keeping the share of EU trade in goods between 15–20 %.

The specific objectives are as follows:

- Environmental impact:
 - Reducing energy consumption in manufacturing activities (– 30 %);
 - Reducing waste generation by manufacturing activities;
 - Reducing the consumption of materials.
- Address social impact:
 - Increasing human achievements in future European manufacturing systems;
 - Creating sustainable, safe and attractive workplaces for 'Europe 2020';
 - Creating sustainable care and responsibility for employees and citizens in global supply chains;
 - Bringing a majority of manufacturing engineering graduates and doctorate holders into manufacturing employment and increasing the opportunities for technician employment.
- Entrepreneurship and innovation:
 - Fostering the creation of technological-based companies around manufacturing of innovative products;
 - Increasing business R & D expenditure in manufacturing.

10.1 Employment

One of the main objectives of the Factories of the Future PPP is to reverse the trend of decline of employment in manufacturing and reinforce the increase of employment in growth sectors.

In 2007, manufacturing enterprises provided employment for 34.5 million persons in the EU. This was equivalent to 26 % of the employment in the EU-27 non-financial business economy. In 2009, the manufacturing sector employed 31 million persons, accounting for 22.8 % within the EU-27's non-financial business economy. As stated in part I of this roadmap, every high-value product or service has a manufacturing process behind it. And every additional (value-creating) job in manufacturing in general leads to a similar amount of 'spillover' jobs in supporting services businesses. Given the difficulty of getting out of the ongoing financial crisis, the Factories of the Future PPP is a key component for reversing this trend.

The Factories of the Future PPP is a multi-sector initiative. The Factories of the Future 2020 roadmap is designed to increase the capability of manufacturing the products of the future in an economic, social and environmentally sustainable way; hence its impact on employment is substantial. It generates impact in a multitude of manufacturing sectors, such as automotive, microelectronics, telecommunications, textile and clothing, health products, household appliances, electrotechnical equipment, machinery, etc. These manufacturers drive a lot of supply chains, including those supplying KETs: advanced materials, biomaterials, raw materials, nanotechnology, biomaterials, etc. In addition, the manufacturing industries rely on the high-tech and high-skilled supply of manufacturing systems and processes (including photonics), ICT and engineering services.

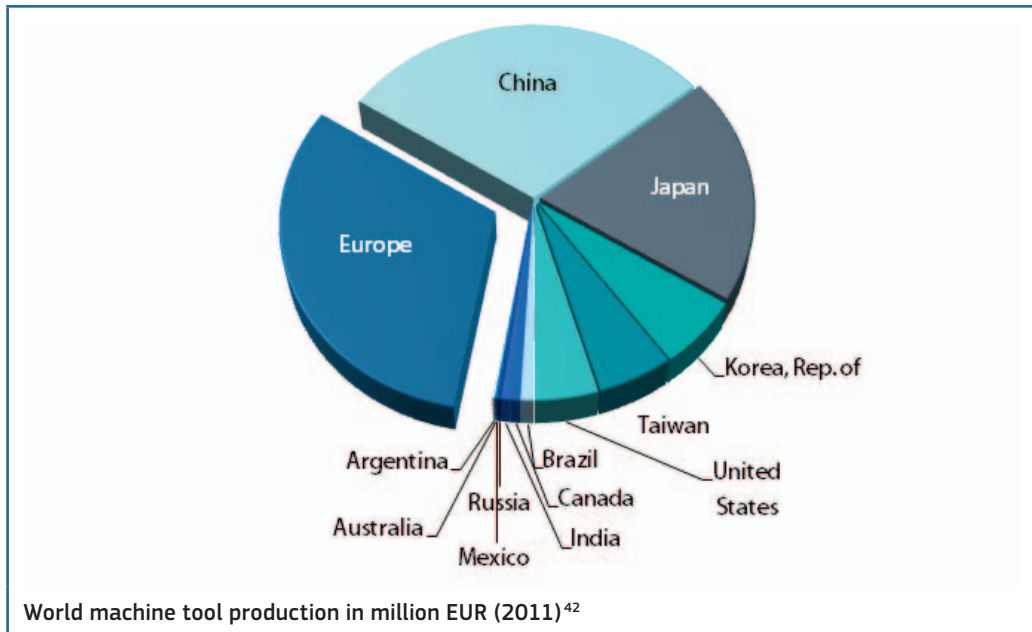
By enhancing the market responsiveness and competitiveness of European manufacturing companies and their suppliers, the Factories of the Future PPP will retain production industries and the dependent supply and service industries in Europe and will in turn stabilise employment figures especially for highly skilled workers. High-tech jobs will be created in European companies, be it manufacturers, machinery and material suppliers, factory builders, automation or ICT companies.

Stabilising and improving employment figures in manufacturing will leverage European citizens' employment more than any other sector, not only in size but also in 'spillover' jobs in the supporting services businesses. Employment is one of the most sensitive issues for welfare and living standards — for individual income and self-respect as much as for the European social and tax system.

10.2 Sustainable competitiveness

The Factories of the Future PPP results will significantly increase the introduction of innovative enabling technologies for manufacturing. They will further improve the profitability of industrial research, increasing revenue by increasing market share, yielding higher added-value product segments, allowing for more investments in longer-term technological competitiveness.

Moreover, the importance of technology leadership in production technologies does not only impact on the competitiveness of manufacturing in Europe, it also sustains Europe as an export leader. For instance, the European share of world machine tool production is 31 %, of which 45 % is exported outside Europe.



In 2009, the manufacturing sector generated EUR 5 812 billion of turnover and in 2010 the figures increased to EUR 6 400 billion.

The Factories of the Future PPP will contribute to reversing the trend of manufacturing moving to low-wage countries. The Factories of the Future PPP will contribute in a qualitative sustainable growth of the manufacturing industry by implementing the strategic shift from 'quality-cost-delivery' competition, which reduces the production cost per good, towards 'value-added production' (including i.e. product individualisation and life cycle orientation). Manufacturing the products of the future will not only have an impact on employment, it will also have an overall impact on the creation of added value, resource efficiency, competitiveness, trade, financial stability and economical welfare in Europe.

More innovative approaches will allow Europe to build on its strengths, maximise its resources (high-valued products based on knowledge-intensive skills and the scarce nature of recycled resources) and make its models more competitive, but also more sustainable.

The Factories of the Future PPP will generate reconfigurable, adaptive and evolving factories capable of high performance and small-scale production. Resource efficiency in manufacturing, including EoL of products, will be linked to environmental sustainability in manufacturing. The Factories of the Future PPP will implement ICT and manufacturing strategies that will support manufacturers and their suppliers in managing the dynamics of supply chains and a need for quick decision-making. The challenging combination of flexibility with productivity, precision and zero-defect manufacturing will be taken to a superior level, generating market responsiveness, quality, efficiency, productivity and maintaining EU leadership in key manufacturing sectors. These are the foundation of European economic competitiveness.

⁴² Source: Cecimo National Indicators; Gardner Publications.

'In short, Europe's recovery and future prosperity depend on our ability to innovate, to bring together research, innovation and education, and to turn new ideas into products, services, jobs and well-being for our citizens'

José Manuel Barroso, President of the European Commission
EU Government and Innovation Conference, Brussels, 8 May 2012

10.3 Societal impact

The societal impact of the Factories of the Future PPP is not only seen in terms of employment, social sustainability in manufacturing is one of the headlines of the roadmap from the perspective of the challenges and opportunities. The role of knowledge-workers is also stressed on the enabling side and there is a specific domain on 'human-centred manufacturing'. Therefore the envisioned impact is:

- increased human achievements in future European manufacturing systems;
- sustainable, safe and attractive workplaces for Europe in 2020;
- establishment of sustainable care and responsibility for employees and citizens in global supply chains.

The technological breakthroughs that will come out of the research work programme of the Factories of the Future PPP will promote the creation of new high-tech working places that demand highly skilled staff. Novel paradigms for manufacturing education, such as the 'Teaching Factory', will further pursue the integration among research, innovation and education, and help prepare the next generation of knowledge-workers that will take over the use of the new technologies within the factories of the future.

Employees will receive positive working experiences and be stimulated by positive emotions since the Factories of the Future PPP abstains from former consideration of people simply as 'human capital' towards complete and emotional humans.

The Factories of the Future PPP stimulates societal cohesion. Manufacturing is the motor for economy all over Europe. World-class manufacturing is the art of integrating white-colour and blue-colour workers more than any other sector. Stimulating the manufacturing sector and providing high-tech, well-paid working places for all will obviously lead to a better social cohesion and mitigate the already existing pay disparity in society better than may (service) sectors that inherently require low-wage jobs. Value added production instead of price competition, demand for higher educated workers that create higher value per hour and thus allow maintaining European wage relations.

The Factories of the Future PPP will foster more attractive high-tech working places in order to be more competitive and to provide working places that offer attractive job opportunities to the next generation of workers, engineers and researchers. 'Intelligent factories' will show new manufacturing environments with multimodal collaboration, advanced human machine interfaces and new forms of cooperation between human and artificial systems. The 'factory of emotion' concept will provide employees with positive working experiences and stimulation by positive emotions as key factors for motivation, concentration and quality work.

New human-machine interaction will improve staff health and safety and leave monotonous economy-of-scale work behind. Altogether, these developments will contribute in lowering the 1.3 million working accidents/year in manufacturing.

Furthermore (and as described under challenges), many products of the future will be designed for health, safety, sustainable mobility, social inclusion and other societal aspects.

- Prostheses, health monitoring and revalidation.
- Not only in purely medical application and products, also integrated in commodities like clothing.
- Safe mobility solutions.

10.4 Environmental impact

Manufacturing is a relevant activity for achieving climate and energy policy objectives. Against a backdrop of an increasing demand for goods and increasing scarcity of resources, it is becoming more and more essential to 'produce more with less'. Innovative manufacturing equipment and processes will make a substantial contribution to the achievement of the '20/20/20' objectives.

The Factories of the Future 2020 roadmap addresses environmental sustainability, while keeping companies competitive to continue along this road in the long run. The efficient and durable use of resources (energy, materials, etc.), the reduction of emissions and waste in manufacturing and the introduction of new manufacturing technologies such as additive manufacturing, 3D printing, etc. are key priorities of the Factories of the Future PPP.

One of the major challenges addressed by the research priorities is to make manufacturing environmentally sustainable, meaning that deploying manufacturing activities is decoupled from the trend of increasing the environmental footprint of manufacturing, by:

- reducing the consumption of energy, while increasing the usage of renewable energy;
- reducing the consumption of water and other process resources;
- near-to-zero emissions in manufacturing processes;
- optimising the exploitation of materials in manufacturing processes;
- co-evolution of products-processes-production systems or 'industrial symbiosis' with minimum need of new resources.

The development and application of innovative enabling technologies for manufacturing will open new ways of producing more goods with fewer raw materials, less energy and less waste. Novel processes, materials and ICT will be addressed, which can deal with the issues pertaining to increased demand for manufacturing goods, finite resources, and environment-conscious production.

On top of that, accelerating and increasing the capability of manufacturing the products of the future leads to a substantial impact on environmental sustainability:

- Manufacturing of energy solutions: photovoltaics, wind energy, etc.;
- Manufacturing of environmental solutions for purification, filtering, recycling, etc.;

- Environmentally sustainable transport solutions, such as electrical and hybrid vehicles through enabling the manufacturing of lightweight solutions, advanced drives, etc.

Impact on the consumption of raw materials

Intelligent, zero-defect, adaptive and product-mix condition manufacturing as promoted by the Factories of the Future PPP will reduce rejections, trial-cases and stock commodities. Current 'economy-of-scale' production lacks reactivity to adapt rapidly to new market demands, which results in production of goods that cannot be sold or that are only sold with price reductions. This causes a waste of energy and raw materials for production and transportation, eventually recycling. While no overall market data is available, in volatile markets like e.g. the toy or consumer electronics market, the uncertainties in the sales prognosis often exceed 40 %.

Impact on the use of energy

Around 28 % of the total energy consumption in Europe comes from industry. In highly industrialised European countries, such as Germany, this percentage rises up to 47 %. Therefore, the impact of a broad introduction of more energy-efficient production technologies in Europe is obvious. The Factories of the Future PPP's environmental sustainability manufacturing theme responds to the need of energy-efficient processes.

The European Commission estimates the energy savings potential by 2020 as being 95 Mtoe, or a full energy savings potential of 25 % by 2020. The achievement of the Factories of the Future PPP's technological objectives is expected to have a significant impact on the achievement of this goal. Regarding the achievable energy savings in manufacturing, energy efficiency is the best alternative and will be the main focus of the related enabling technologies to be considered by the Factories of the Future PPP.

A study from 2009⁴³ predicted that innovative production equipment and processes would save, in the following 10 years, 325 PJ in the production sector in Germany (which corresponds to the electricity consumption of around 24.9 million households). With regard to reduction of greenhouse gases, this is the equivalent of 34 million tons of CO₂ savings. In terms of percentage, an improvement of energy efficiency of around 12 % for the production sector and of approximately 16 % for all sectors using engineering products is expected for the following 10 years.

Research and innovation play an essential role in realising this potential. Efforts from both the private side and the public side are needed to make the necessary investments in RD & I for energy-efficient production equipment. Because of this huge potential, both in terms of energy efficiency and economic opportunities, investments in research on efficient production promise substantial leverage effects and impact potential.

The Factories of the Future PPP will foster these leverage effects by making energy efficiency one of the priorities of their strategy, by bringing the relevant industrial actors together,

⁴³ VDMA — Verband Deutscher Maschinen- und Anlagenbau, Roland Berger Strategy Consultants (Hrsg.): Der Beitrag des Maschinen und Anlagenbaus zur Energieeffizienz.

establishing a more long-term and stable investment framework, thus encouraging the necessary private investment. Based upon these factors, it is expected that the PPP will substantially contribute to reducing energy consumption, energy costs and CO₂ emissions.

In addition, the progress of manufacturing and engineering technologies will have a twofold impact on competitiveness: Firstly, the reductions have a direct impact on the production costs and reduce the dependency on energy supply. Secondly, on the demand side, energy efficiency is a main driver for new markets and business opportunities and will provide a competitive advantage to suppliers of this equipment.

Impact on the generation of hazardous emissions and waste

Manufacturing generates about 400 million tons of waste of which 10 % are hazardous, which is twice as much as households and half of construction. Reducing waste in manufacturing will therefore contribute greatly to improving the environmental performance of the factories of the future. Sustainable manufacturing, new processes, such as generative ones which neither require lubricants nor generate chippings waste, self-optimising production and processes and adaptive manufacturing bring those reductions in waste.

ICT for example could play a significant role in mitigating up to 970 million tons of global carbon emissions by 2020, thanks to motor systems and industrial process optimisation. The Factories of the Future PPP will significantly contribute in the achievement of this goal.

10.5 Impact on the research and innovation potential of Europe

A highly positive impact is expected on research and innovation, by pooling together resources within a coordinated and integrated work programme and promoting more efficient resource allocation to technological areas of strategic interest for the European manufacturing industry. This would ensure a consistent approach. It would help to avoid dispersed actions resulting from funding decisions that reflect different research programme priorities. It would also allow aligning the pace of calls for proposals with the pace of developments in the respective technological themes. And in combination with smart regions that specialised in manufacturing new eco-systems of suppliers around larger OEM industries will emerge faster and more successfully.

As already mentioned under 10.2, the Factories of the Future PPP results will significantly increase the introduction of innovative enabling technologies for manufacturing, resulting in an increasing profitability of industrial research and increasing revenues in higher added-value product segments, generating investments in longer-term technological competitiveness.

Significant benefits are further expected by the research synergy of all key manufacturing stakeholders, including both manufacturing equipment/ICT suppliers/factory builders and a very broad range of users. A greater visibility and a more effective exploitation of R & D outputs are envisaged, which will result in increased competitiveness and sustainability for the entire EU industry. The expected reduction in the time-to-market for research outputs will also allow manufacturing industry to accelerate their transformation into new products and processes, and improve its innovation performance.

11 Additionality to existing activities — the added value of action at EU level

Investments in R & D and innovation by nature bear investment risks. It is not possible to predict either the technological success of a research project nor the innovation and market success deriving from a project. However, during FP7, the Factories of the Future PPP has demonstrated the existence of several critical success factors which increase substantially the innovation and impact potential of a research and innovation programme⁴⁴.

In summary, the Factories of the Future PPP demonstrates the following clear benefits and additionality:

- The establishment of a multi-annual integrated work programme, ensuring a long-term continuity in the implementation of manufacturing research strategies.
- Industry has a leading role in defining research priorities, timelines, and rules. Industry co-decides and manages the implementation; through its strong industry participation in both programming and project execution, Factories of the Future involves the stakeholders which are close to the needs of markets and customers and who are more likely to be familiar with new challenges and opportunities, which will lead to improved focusing of resources and activities.
- Single (integrated) management structure to mobilise all the funds assigned to the research programme from the public and the private sectors. No fragmentation of RTD governance.
- Factories of the Future is a targeted initiative. Through its industrial relevance, transparency and clear thematic focus, Factories of the Future is attractive for industry participants and, in particular, for newcomers to the European framework programmes.
- Pre-defined budget for a long-term horizon raises confidence in private sector investors and encourages industry to make long-term investment plans. Incentives will be provided to industry and Member States, attracting additional national support and leveraging a greater industry funding.
- The work programme goes from fundamental and applied research through to industrial pilots and large-scale demonstration, bringing research outputs closer to market.
- By bringing together different technologies and through an integrated and multidisciplinary approach, Factories of the Future will help to identify technological barriers, maturity/supply chain gaps and synergies.
- Increased use of SME-friendly research instruments with a possibility to develop also new measures.
- Reduced time-to-contract and efficient follow-up.

⁴⁴ See 'Analysing and evaluating the impact on innovation of publicly funded research programmes', Report to Lot 2 of European Commission Tender ENTR/04/96.

- Increased process transparency for industry, more experts/evaluators coming from industry.
- More emphasis on industrial innovation and impact on the realisation of manufacturing strategies and roadmaps, boosting the knowledge level and stimulating exploitation.
- The Factories of the Future PPP enables the network and links between the relevant actors. Networks between the relevant actors enable the flow of knowledge and mutual learning. Due to the widening community, it is expected that results are disseminated in an effective way and that there is a substantially higher potential for transactions, uptake, exploitation and post-research activities. It will create a European Factories of the Future research community, which facilitates the transfer of results, generates synergies and knowledge spillover and will finally lead to a substantially higher effectiveness of research expenditure. In particular, SMEs will have a unique opportunity to work with major business and research organisations which will provide them with new technological knowledge and business opportunities.

The following table gives an overview of the advantages to further build upon the FoF PPP created in FP7:

Impact	Business as usual (= EU FP and national/ regional instruments)	Factories of the Future PPP
Governance	Fragmentation of RTD governance across a number of different national and regional schemes and different FP themes. Management on the basis of annual work programmes; research priorities and timelines defined by EC, consultations with other stakeholders. Industry not involved in management of the overall RTD action.	Industry has the leading role in defining research priorities, timelines, and rules, in consultation with the research community and the European Commission. Multi-annual integrated roadmap, ensuring a long-term continuity in the implementation of manufacturing research strategies
Industrial involvement	Manufature provides advice on topics for annual work programmes and stimulates proposals that reflect industrial priorities.	EFFRA, representing industry (large enterprises and SMEs, research organisations and universities), is actively involved in strategy definition and advice on work programme development. Industrial participation in projects is higher than 50 %, SME participation is 30 %.
Planning/ budget horizon	No ring-fenced funding for specific technologies. Work programme topics decided annually, leading to uncertainty as industry cannot plan RTD investments more than one year ahead.	Pre-defined budget reduces funding risks. Pre-defined budget for a long-term horizon raises confidence in private sector investors and allows industry to make long-term investment plans and manage its cash flows.
Research implementa- tion	Small to large-scale projects, mainly focusing from basic to applied research activities. Projects commonly terminate, are stuck or slowed once the basic research ends, resulting in limited commercial exploitation.	Research activities go from applied research through to industrial pilots and demonstration, bringing research outputs closer to market.
Procedures	Proven openness and transparency of RTD framework programme. Often heavy administrative burden associated with proposal preparation, contract negotiation and reporting.	FP principles of openness and transparency and provisions of the financial regulation also applied. Increased process transparency for industry. Streamlined procedures and faster project selection, reduced time-to-contract and efficient follow-up.
Project selection	Respected peer review process managed by EC. Emphasis on scientific quality and technical excellence more than realisation of a strategic portfolio according to industrial priorities, hence a risk of technology gaps.	Increased number of experts/evaluators coming from industry. Besides scientific/technical excellence, industrial innovation and impact on the realisation of manufacturing strategies and roadmaps also considered.

12 Expected impact of achieving the specific research and innovation objectives

The Factories of the Future 2020 roadmap is organised in domains that regroup research and innovation priorities. These priorities are addressing the challenges and opportunities, as described in part II of this document. The impact generated by the research domains on the respective challenges and opportunities is illustrated by the table below (rating the impact from 1 (minor) to 5 (very strong)).

		DOMAIN 1: ADVANCED MANUFACTURING PROCESSES	DOMAIN 2: ADAPTIVE AND SMART MANUFACTURING SYSTEMS	DOMAIN 3: DIGITAL, VIRTUAL AND RESOURCE-EFFICIENT FACTORIES	DOMAIN 4: COLLABORATIVE AND MOBILE ENTERPRISES	DOMAIN 5: HUMAN-CENTRIC MANUFACTURING	DOMAIN 6: CUSTOMER-FOCUSED MANUFACTURING
MANUFACTURING THE PRODUCTS OF THE FUTURE		5	2	5	3	2	5
ECONOMIC SUSTAINABILITY OF MANUFACTURING							
	Addressing economic performance across the supply chain	5	4	4	5	3	4
	Realising reconfigurable, adaptive and evolving factories capable of small scale production	3	5	5	5	3	3
	High performance production, combining flexibility, productivity, precision and zero-defect while remaining energy-efficient	5	5	5	3	3	2
	Resource efficiency in manufacturing, including addressing the end-of-life of products.	5	3	5	5	2	5
SOCIAL SUSTAINABILITY OF MANUFACTURING							
	Increase human achievements in future European manufacturing systems	3	5	5	4	5	4
	Creating sustainable, safe and attractive workplaces for Europe 2020	5	5	5	4	5	2
	Creating sustainable care and responsibility for employees and citizens in global supply chains	2	3	3	3	5	5
ENVIRONMENTAL SUSTAINABILITY OF MANUFACTURING							
	Reducing the consumption of energy, while increasing the usage of renewable energy.	5	5	5	5	1	3
	Reducing the consumption of water and other process resources.	5	2	5	5	2	2
	Near to zero emissions in manufacturing processes.	5	5	3	4	3	3
	Optimising the exploitation of materials in manufacturing processes	5	4	4	3	2	2
	Co-evolution of products-processes-production systems or 'industrial symbiosis' with minimum need of new resources	4	3	3	4	1	4

This provides the baseline for measuring the impact of the respective domains.

13 Monitoring and assessing progress

Monitoring and assessment of the progress towards achieving the desired effects and expected impact of the Factories of the Future PPP is critical. It will enable the steering of the Factories of the Future programme in terms of the planning of research priorities and the choice of the appropriate funding instruments (small, large, demo-projects, etc.). It will furthermore provide information that will help identify the actions required to stimulate further uptake of project results, driving them to TRLs beyond 7.

Thus a set of key performance indicators (KPIs) should be identified in order to help assess the impact and progress.

The assessment of relevant European and international impact-monitoring activities has helped in identifying some relevant KPIs that may be used as a basis for monitoring the overall impact from the future implementation of the Factories of the Future 2020 roadmap. In the following paragraphs, this by no means exhaustive set of performance indicators is introduced.

13.1 Monitoring operational performance indicators

The following operational performance indicators have been identified:

- time-to-grant;
- number of running projects, number of participating organisations;
- level of industrial and particularly SME participation;
- geographical coverage of Factories of the Future projects participation;
- budget share devoted to demos and prototyping.

13.2 Monitoring innovation capacity and socioeconomic impact

The following performance indicators have been identified:

At PPP implementation level:

- New systems and technologies developed in the relevant sectors
- Participation and benefits for SMEs
- Contribution to the reduction of energy use
- Contribution to the reduction of waste
- Contribution to the reduction in the use of material resources
- New high-skilled profiles and new curricula developed
- Private investment mobilised in relation to the PPP activities
- Contributions to new standards

At project impact level:

- Scale of reduction in energy, material resources and waste
- Project results taken up for further investments
- Training provision for a higher quality workforce
- Patents and activities leading to standardisation

Through the execution of the Factories of the Future PPP in Horizon 2020, the European manufacturing community expects a significant increase in scientific publications, patents and licences. Scientific publications, patent data and licences provide a relevant source for an empirical measurement of 'technology competitiveness'. Patent applications refer to technical inventions that have reached a certain state of feasibility and thus represent the successful completion of some stage of R & D efforts. Most patents are applied by firms and so are linked to their competitive strategies. Although comparability of patent data is limited due to different economic values a patent may represent different degrees of technological novelty and different regulations of national patent offices. Patent data are nevertheless a useful source to analyse dynamics in certain fields of technology. This approach is coherent with the considerations on impact assessment measures that have been included in the draft Horizon 2020 programme for the overall 'Industrial Competitiveness' Pillar.

Beyond monitoring new patent applications and licences that originate from Factories of the Future PPP projects, further indicators will be developed that can quantify products that are put on the market and that are protected by these new patents or generated from licence agreements.

13.3 Monitoring impact using S & T performance indicators on a project level

This concerns the monitoring of the achievement of technology-specific milestones on the level of research priorities (e.g. correlating the deployment of specific technologies — mechatronics, ICT — with the reduction of energy consumption in a specific application area). These performance indicators will be monitored on the basis of a systematic follow-up of the technological progress of the Factories of the Future projects considering the research priorities, challenges and the enabling technologies that the projects address. The monitoring will be supported by EFFRA's projects and roadmap database.

13.4 Network analysis

Collaboration is extremely relevant for future R & D and innovation. Network analysis could be used to address this aspect. It allows network mapping and measuring relationships and linkages among researchers, groups of researchers, laboratories, or other organisations. Network analysis is relevant to evaluation of R & D programmes because it identifies routes of interactions by which ideas, knowledge, and information flow among participants in R & D, thereby possibly influencing the nature, quality, quantity, and speed of research and innovation, as well as the dissemination of created knowledge through the network. The underlying concept is that the conduct of science is a social activity collectively performed and resulting in 'communities

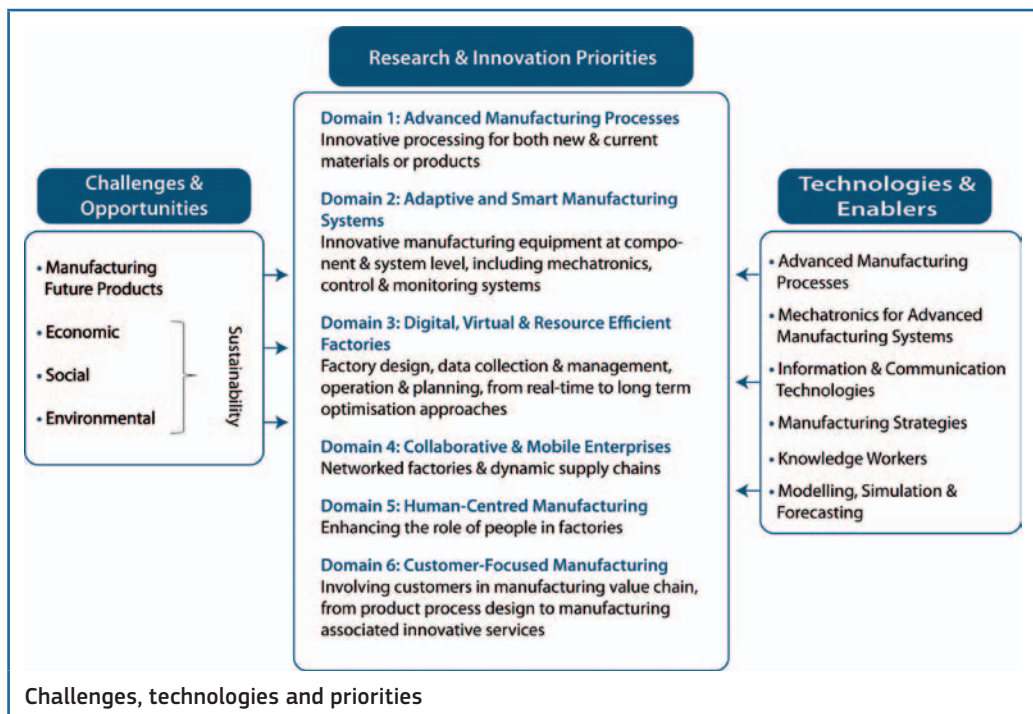
of practice'. Advances in knowledge stem from knowledge-sharing and knowledge-combining activities. Networks can link researchers to a rich flow of ideas and information. A network of researchers creates a knowledge system that may yield much more than the individuals acting independently. The network analysis method, which examines flows of knowledge into and through the social network, is seen as a promising approach to understanding, predicting, and improving knowledge outcomes. Network shape, size, and density can serve as indicators of the strength of communities of practice and signal relative roles and relationships.

Innovation is central to the Factories of the Future initiative strategic perspective. Nowadays, most innovations involve a multitude of organisations and this is especially the case for the most knowledge-intensive technologies like ICTs. Thus, network analysis is considered to be a very relevant innovation metric for the impact assessment of the Factories of the Future PPP roadmap.

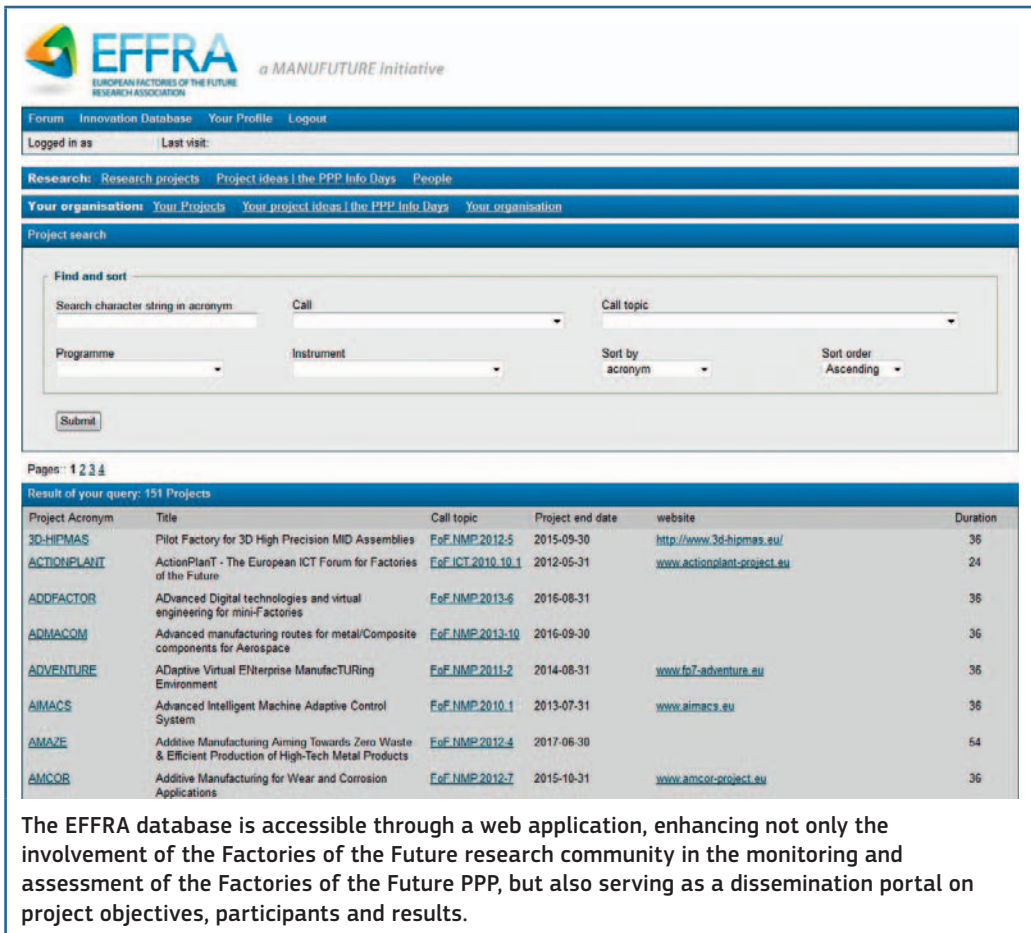
13.5 Systematic monitoring and stimulation of the uptake of project results

13.5.1 Project and roadmap database and web application

The monitoring and assessment of progress of the Factories of the Future PPP will be supported by a database and web application. It will support the systematic mapping of the challenges and opportunities and technologies and enablers by the proposed research and innovation priorities.



In addition, the EFFRA database contains the public information of the Factories of the Future projects. The projects will be continuously mapped on the research and innovation priorities and their associated challenges/opportunities and technologies/enablers. This way, a systematic monitoring of the impact of the Factories of the Future projects will be carried out in terms of addressing challenges, exploiting opportunities and developing and deploying technologies for innovation in manufacturing.



The screenshot displays the EFFRA web application interface. At the top, the EFFRA logo is shown with the text "a MANUFUTURE Initiative". Below the logo, there are navigation links: "Forum", "Innovation Database", "Your Profile", and "Logout". A status bar indicates "Logged in as" and "Last visit:". The main navigation menu includes "Research", "Research projects", "Project Ideas", "The PPP Info Days", and "People". Below this, there are links for "Your organisation", "Your Projects", "Your project Ideas", "The PPP Info Days", and "Your organisation". The "Project search" section features a search form with fields for "Find and sort", "Search character string in acronym", "Call", "Call topic", "Programme", "Instrument", "Sort by", and "Sort order". A "Submit" button is located below the search form. Below the search form, the results are displayed as a table with the following columns: Project Acronym, Title, Call topic, Project end date, website, and Duration. The table lists 151 projects, with the first few rows visible.

Project Acronym	Title	Call topic	Project end date	website	Duration
3D-HIPMAS	Pilot Factory for 3D High Precision MID Assemblies	FeF NMP 2012-5	2015-09-30	http://www.3d-hipmas.eu/	36
ACTIONPLANT	ActionPlanT - The European ICT Forum for Factories of the Future	FeF ICT 2010 10 1	2012-05-31	www.actionplant-project.eu	24
ADDFACTOR	ADvanced Digital technologies and virtual engineering for mini-Factories	FeF NMP 2013-6	2016-08-31		36
ADMCOM	Advanced manufacturing routes for metal/Composite components for Aerospace	FeF NMP 2013-10	2016-09-30		36
ADVENTURE	ADaptive Virtual ENterprise ManufacTURING Environment	FeF NMP 2011-2	2014-08-31	www.fe7-adventure.eu	36
AIMACS	Advanced Intelligent Machine Adaptive Control System	FeF NMP 2010 1	2013-07-31	www.aimacs.eu	36
AMAZE	Additive Manufacturing Aiming Towards Zero Waste & Efficient Production of High-Tech Metal Products	FeF NMP 2012 4	2017-06-30		64
AMCOR	Additive Manufacturing for Wear and Corrosion Applications	FeF NMP 2012-7	2015-10-31	www.amcor-project.eu	36

The EFFRA database is accessible through a web application, enhancing not only the involvement of the Factories of the Future research community in the monitoring and assessment of the Factories of the Future PPP, but also serving as a dissemination portal on project objectives, participants and results.

13.5.2 Organisation of workshops and clustering events

EFFRA will organise, on a yearly basis, workshops aiming at the exchange of expertise and stimulating cross-fertilisation among the Factories of the Future research and innovation community. It is also considered to involve experts from the European Investment Bank (EIB), joint venture capitalists and other experts on market uptake and technology transfer.

These workshops will furthermore support the monitoring of progress and impact of the FoF programme.

Part IV: Governance

14 The governance model between EFFRA and the European Commission for the Factories of the Future PPP in Horizon 2020

EFFRA and the European Commission services started working on the Factories of the Future PPP in FP7 some 5–6 years ago. During these years the two sides have developed a good working relationship and it is now time to formalise these working methods and establish a partnership board for the PPP in Horizon 2020.

While the basic principle of the PPP is specified in Article 19 of the Horizon 2020 regulation, the roles and duties of private and public parties will need to be more specifically described in a written memorandum of understanding (MoU) which will form the basis of the future partnership. Due to the nature of EU and national budgetary laws, an MoU is not legally binding for either side.

The MoU will specify the indicative financial envelope of the European Commission contribution for the years 2014–20. As was the case for the FoF PPP in FP7, the FoF 2020 PPP shall be implemented through competitive calls included in the Horizon 2020 research work programmes and with the rules for participation of Horizon 2020.

The partnership board will be the body where the private and public side meet on a regular basis, and jointly work on the preparation of the work programmes that are relevant for the Factories of the Future PPP. EFFRA will delegate the private-side members of the partnership board, which will consist of representatives from key industries, including SMEs, research centres and universities. These members will commit themselves to provide advice in their relevant fields of expertise to the best of their ability and in the best interest of Community research.

EFFRA will need to be granted some form of freedom to establish appropriate consultation processes to ensure the adequate involvement of all relevant stakeholders in the preparation of the inputs to the Commission.

EFFRA representatives shall also be entitled to attend, when considered necessary, the relevant programme committees in order to allow Member States' representatives to clarify any questions they might have on the roadmap implementation.

14.1 Information and results sharing

By undertaking a widespread dissemination of activities, EFFRA is not only promoting the Factories of the Future partnership and projects but also guarantees that this information is available to the public in an accessible manner.

To achieve widespread dissemination of information on projects and activities, EFFRA uses a number of communication tools that are open to the public as well as publications available for free.

Information on all existing Factories of the Future PPP projects and the complete Factories of the Future 2020 roadmap is and will continue to be available to the public at no charge through EFFRA's website.

EFFRA organises, supports and participates in numerous events to facilitate the open discussion of industrial research priorities, project activities and results, cross-programme/international cooperation and potential opportunities/challenges facing European industry.

EFFRA has developed a unique projects database and regularly publishes project brochures.

14.2 Openness, transparency and representativeness

Overall mission of EFFRA

The chief mission of EFFRA is to act as the representative of the private side in the Factories of the Future public-private partnership, developing its research priorities, disseminating information and promoting the partnership and its pre-competitive cooperation. EFFRA is committed to operating in a fair and transparent manner in keeping with the concept of cooperative pre-competitive research. Along with its industrial relevance and available support, transparency is an important factor in attracting industrial participation in the Factories of the Future public-private partnership. As an industry-driven association this is also the case for EFFRA.

The development of the Factories of the Future 2020 roadmap has been an exercise in openness in keeping with the aforementioned principles of fairness and transparency. This has been achieved through a widespread, multi-sector stakeholder consultation followed by two public consultations. After amendments based on the input received through these consultations, the roadmap was made publically available for a third time for validation.

Structure

From its establishment in 2008/2009, EFFRA has been designed to operate in a transparent way.

EFFRA has been set up as an international not-for-profit association under Belgian law. Any company, research organisation, university, NGO, trade union or sector association that deals with production technologies is invited to join EFFRA. Today, some 140 organisations are full members, and thousands of other companies and RTOs are indirect members through the many associations and innovation alliances. Within the structure of the association, the decisions of the board of directors and of the secretariat are subject to the scrutiny of, and approval by, the members. A general assembly of members takes place on an annual basis to ensure that members can examine, question and decide upon issues affecting the association and its priorities. In keeping with the principles of fairness and transparency found in Framework Programme 7 the statutes of the association require members to act in an ethical and transparent manner.

Serving the wider Factories of the Future community

Since its foundation, EFFRA has engaged with organisations involved in, or interested in becoming involved in, the Factories of the Future partnership regardless of their membership or non-membership of EFFRA.

While EFFRA makes numerous services available to members, this does not detract from its partnership support activities which involves collaboration with organisations throughout Europe.

15 Conclusion and outlook

Recognising the need for a representative body to speak on behalf of the private partners in the Factories of the Future public-private partnership, in 2009 the manufacturing community formed the international non-for-profit association European Factories of the Future Research Association (EFFRA). The association is composed of over 100 members including industries (both large and SME), research and technology organisations (RTOs), universities and related European associations.

This document has been developed by EFFRA through numerous internal and external consultations over a period of 24 months. Meetings included discussions with representatives of the European Commission within the Factories of the Future PPP Ad hoc Industrial Advisory Group (AIAG) and close consultations with representatives of companies and RTOs organised in other related European technology platforms.

An extensive public consultation on this roadmap took place in summer/autumn 2012. The consultation was publicised through the communication tools and social media of EFFRA, platforms and related stakeholders. It provided companies, RTOs, universities, European technology platforms, associations, NGOs, trade unions and other groupings with an interest in manufacturing with the opportunity to provide their input. A continuous dialogue with other PPPs is furthermore taking place.

The present document endeavours to reflect the feedback obtained during the public consultation. Should you have any question on this document, please contact info@effra.eu.

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European Commission

FACTORIES OF THE FUTURE

Multi-annual roadmap for the contractual PPP under Horizon 2020

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Industrial production accounts for 16% of Europe's GDP and remains a key driver for innovation, productivity, growth and job creation. In 2009, 31 million persons were employed in the EU manufacturing sector, and each job in manufacturing generates at least an additional job in services. Moreover, nowadays 80% of the EU's exports are manufactured products. However, Europe's position as an industrial power house is eroding and its leadership in many important sectors is constantly challenged.

Under the new EU framework programme Horizon 2020, the contractual Public-Private Partnership (PPP) on Factories of the Future builds on the successes of the Factories of the Future PPP launched under the European Economic Recovery Plan in late 2008, which selected 150 high level projects involving top industrial companies and research institutions in Europe.

This multi-annual roadmap for the years 2014-2020 sets a vision and outlines routes towards high added value manufacturing technologies for the factories of the future, which will be clean, high performing, environmental friendly and socially sustainable. The priorities included were agreed among the wide community of stakeholders across Europe, after an extensive public consultation. With the engagement of the EU manufacturing industry, this PPP is expected to deliver the technologies needed for the new European factories of the future, highly sustainable and competitive.



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