Roadmaps Executive Summary[1]

15 July 2010

[1] This is the Executive Summary of the roadmaps on: (1) Sustainable Manufacturing, Energy Efficient Manufacturing and Key Technologies (2) Standardisation and (3) Innovation, Competence Development and Education

1. Introduction

The Roadmaps developed in the IMS2020 project focus upon the identification of relevant manufacturing research topics and supporting actions which need to be fostered through international cooperation between 2011 and 2013. These are critical Research Topics, grouped in Research Actions which - when implemented - will allow the achievement of the defined IMS2020 Vision and thus the shaping of manufacturing systems by the year 2020 and beyond (Figure 1).
The Roadmaps depicted in this report depart from the implementation of the identified research topics and supporting actions between 2011 and 2013, and show the possible impacts or benefits that these could deliver in a timeline towards the IMS2020 Vision.

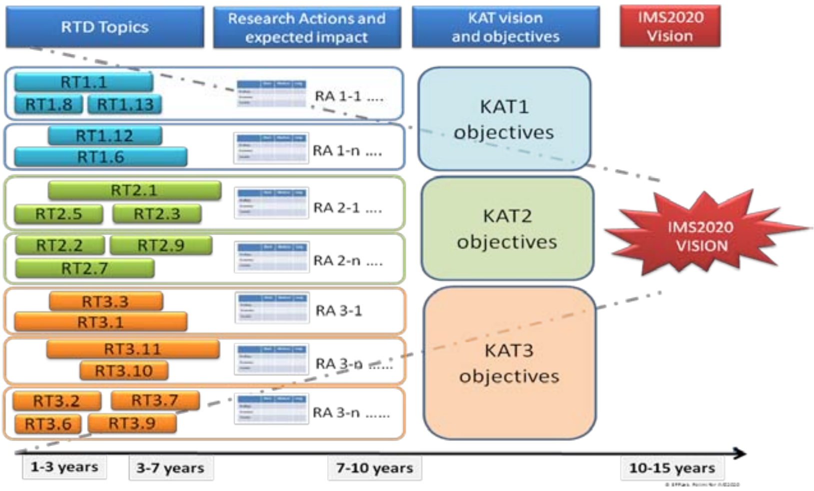

Figure 1: Structure of the work; Research Topics, Research Actions and Key Areas toward the IMS2020 Vision

The Roadmaps has been developed with an approach designed to ensure the highest relevance to input coming from the industrial community as well as to ensure the international (IMS Regions) relevance to the results. Moreover, the work has kept into high consideration the work already and recently done both at European and International level on proposing roadmap in the field of manufacturing. Specifically, 20 world-wide existing roadmaps and 13 ongoing research projects have been mapped, identifying a total of 754 Research Issues.
The development of the Roadmaps has been supported by collaborative tools shared with all the Roadmapping Support Group, a growing community that, presently, counts 254 participants from 108 mainly industrial organizations.
The elaboration of the research agenda topics was conducted via consultation. This process included an open online survey, with 261 participants, two brainstorming workshops and 106 interviews. All these activities involved experts not only from Europe, but from all over the world, with special focus on the IMS regions (Japan, Korea, US). A synthesis of the individual agenda contributions was then produced by the IMS2020, resulting in a vision for the 2020 manufacturing, comprising a set of 62 Research Topics, judged to be instrumental for its realisation. These topics have been shared and fine-tuned with the input

of the community through an online wiki (http://ims2020net.wik.is/) that had more than 2500 visits up to now. Finally the research topics have been prioritized (e.g. Figure 2) through a second online survey, with 359 participants, which also address the interest of the different IMS regions to participate into collaborative research projects on each single Research Topic (e.g. Figure 3).

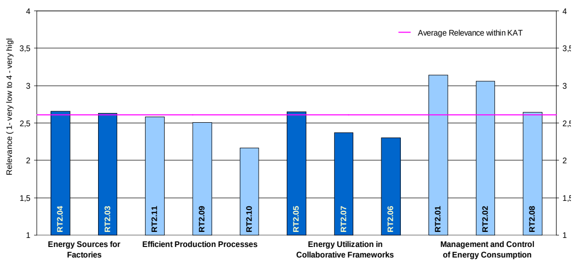

Figure 2: Overall relevance of the Research Topics in Energy Efficient Manufacturing

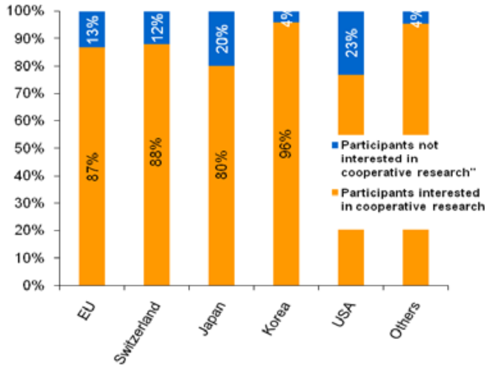

Figure 3: Example of Regional Interest for Collaboration, for topic "Sustainable SMEs"

2. The IMS2020 Vision

The IMS2020 Vision for the future of manufacturing can be realistically materialized via targeted international collaboration in the identified Research Topics and their supporting actions. The main elements of IMS2020 vision can be summarised as follows:

1. *Rapid and adaptive user-centred manufacturing which leads to customised and 'eternal' life cycle solutions.*
2. *Highly flexible and self-organising value chains which enable different ways of organising production systems and related infrastructures, while reducing the time between engaging with end users and delivering a solution.*
3. *Sustainable manufacturing culture, from individual attitudes all the way up to corporate governance, supported by the enforcement of rules and a proper regulatory framework co-designed between governments, industries and societies and facilitated by adequate training, in line with EC's Strategic Framework for Education & Training, ET 2020.*

The vision has been specified till now into 3 IMS Areas of interest. These are presented in the following.

3. Sustainable Manufacturing, Products and Services

After years of relative inaction, the vision of sustainable development and sustainable manufacturing is now markedly growing in importance. Both the market and the consumers are increasingly becoming eco-aware, demanding that sustainability issues are adequately addressed.. At the same time, the regulatory framework is being adjusted and is

under continuous development to fit the growing requests and requirements for sustainability metrics and rating. A high score in this rating is understood to yield a competitive advantage.
Moreover, with the increase of resources and energy price, it's a key aspect to manage correctly their shortage. All these issues are making sustainability a key aspect to be taken into consideration in business, business models and technological developments.

The sustainable manufacturing vision is still far to be achieved, therefore has to be the basis of future researches and developments. Moreover, due to globalization, the sustainability issues have to be analyzed and developed not only at national or regional level, but guidelines and regulations have to be done at worldwide level.
For this reason, within the IMS2020 roadmap, sustainability has a great role, aiming at improving the sustainability of technologies, products and production systems as well as the businesses behind them.
According to this vision and this focus, the main Research Actions identified are:

- *Scarce Resources Management*
- *Technologies for Sustainability*
- *Sustainable Lifecycle of products and production systems*
- *Sustainable Product and Processes*
- *Sustainable Businesses*

These actions and the research topics they address, are briefly presented in the Annex of this document (Annex A).

4. Energy Efficient Manufacturing

Manufacturing is playing a core role when it comes to green house gases (GHG) and final energy consumption. With 33% of final energy consumption and 38% of direct and indirect CO_2 emissions, manufacturing industry has the biggest share in both.
From the companies' point of view the importance of energy efficient manufacturing has various reasons, such as customers changing their purchasing behaviour with regard to "green" products and services, rising energy prices, or emerging of new environmental regulations. Using the available energy more efficiently is a way to meet ever-rising energy needs and secure energy supplies.
The IMS2020 Key Area "Energy Efficient Manufacturing" aims for reducing the scarce resource depletion as well as the carbon footprint by considering innovative methods and technologies. Products and processes are no longer just subject to cost and quality. According to this vision there are four major areas for research and action (Annex B):

- *Energy Sources for Factories*
- *Efficient Production Processes*
- *Energy Utilization in Collaborative Frameworks*
- *Management and Control of Energy Consumption*

5. Key Technologies

In the manufacturing sector the main technological driver has been the productivity growth while reducing costs. In the next decade, in a view of global markets and networking manufacturing communities, state-of-the-art technologies will continue playing that key role because this time manufactures will demand value-adding, competitive and sustainable manufacturing systems and processes along their entire lifecycle, so that appropriate enabling technologies will be required for that ambitious goal. Indeed, technologies such as e.g. intelligent cognitive elements, adaptive systems, diagnostic features and multi-disciplinary simulations will establish the basis for allowing system builders to deliver to customers customised configurable systems at reduced costs and minimised lead-times, and in turn, will allow the users to embed value into their manufactured final products along highly efficient production processes.

Within this vision, the IMS2020 Key Area “Key Technologies for Manufacturing” aims at developing the technologies for allowing system builders to produce value-adding systems at minimised costs and environmental impacts and for allowing the users of said systems to produce value-adding customised products with increasingly shorter delivery times and of high technological content. In particular, four areas are proposed for that research:

- *Flexible Manufacturing Systems*
- *Cost-Saving Manufacturing Systems*
- *Energy-Saving Manufacturing Systems*
- *Key Technologies embedded in manufactured products*

In the following annex, all the Research Actions and the needed Research Topics to fulfil them are presented. Key Technology is described in Annex C.

6. Standards

Enforced by today’s pressure for sustainability and energy-efficiency, norms and standards are turning into the focus of the economy and even more into the central focus of corporations. In this context, special attention needs to be drawn to the achievement of a standardized, sustainable and energy-efficient production. The inherent value of these standards is significant from an economic as well as from a business perspective. From a business perspective, corporate norms are constituted of well-established information that can be accessed by all organizations. Consequently, they represent a dominant instrument for a significant reduction of transaction costs. Furthermore, organizations are able to reduce the risk of their research and development activities as well as for their research and development costs. From an economic perspective, standards and norms do have a greater effect on the growth of the economy as patents and licenses do. They e.g. represent an essential part of the entrance strategies for the international market. Above all, international standards and norms do have a catalyst character, which leads to a faster diffusion of new technological knowledge and subsequently, to the enhancement of the technological transition. This illustrates that standards and norms play a fundamental role in the spread of innovative and sustainable processes, technologies and products. Next, they become the crucial factor for the establishment of sustainable products and services and thus encourage the entire economic progress. In this way, standards do pave the way for the necessary and future oriented connection of the success for businesses and the good of the economy.

Whereas the IMS2020 project roadmaps for the key areas sustainable manufacturing , energy efficient manufacturing and key technologies mainly stimulate the innovations, they have to be supported by standards ensuring the efficient diffusion of innovations into the market. Therefore IMS2020 Standards roadmap aims to support the achievement of the proposed research topics and thereby the achievement of the whole IMS2020 vision. Hereby the support is not limited to the consolidation of existing standards. Much more the roadmap shall be the building block for the collaborative research and development of new internationally accepted standardization actions.

The various standards supporting intelligent manufacturing have been segmented into six standards clusters:

- *Interface standards,*
- *Measurement standards,*
- *Process standards,*
- *Safety standards,*
- *Product and component standards and*
- *Material standards.*

These standard clusters were matched with the research topics . In addition the research topic orientated relevance of standards was aggregated. Based on the derived main driving standard clusters the standards specific Manufacturing Technology Platform could be proposed. MTPs describe knowledge sharing platforms for researcher groups that are already engaged in a specific R&D domain. Through such MTPs projects with non-proprietary or non-competitive overlapping research could join to push R&D activities in standardization on an international level. Each MTP proposal aggregates the standardization needs aligned with the future research topics of IMS2020.

7. Innovation, competence development and education

Human resources and competence for science and technology are vital to economic growth because highly skilled people are needed to perform new innovations. In most countries, the demand for skilled people is expected to increase due to global competition and need for knowledge to handle advanced technologies. This reflects an increasing need for highly skilled workers across the economy as a whole.

Manufacturing has moved from a pure technology view to a view integrating technology, business and management. The extended view on manufacturing reflects a need for a new competence for the industry. The future manufacturing engineer must be trained for the integrated view and must at the same time manage the societal needs for sustainability and environmental protection.

Following basic **Research Topics** have been developed to meet future challenges on competence development and education (see Annex D):

1. Teaching factories
2. Cross sectoral education

3. Communities of practice
4. From tacit to explicit knowledge
5. Innovation agents
6. Benchmarking
7. Serious games
8. Personalized ubiquitous learning
9. Accelerated learning

In the global market, with the emergent economies, European enterprises have challenges in surviving unless they are capable to leverage successfully their capacity to innovate. Enterprises in almost all sectors are forced to develop innovative products in shorter cycles due to market constraints. In response to the pressure resulting from competing in a global market, enterprises follow two major trends:

- Open Innovation.
- Extended Products

The key challenge with innovation is to understand that it is more than the act of inventing something new, in fact, the processes supporting innovation is quite complex and change as an idea is seeded until it reaches the market as a product or service. Following focus areas are relevant.

- Global Brain
- Learn to Innovate
- Go Green
- Living Labs
- Risk Management.
- Sustainable new apprenticeships

Annex: IMS2020 Research Topics

A. Sustainable Manufacturing, Products and Services.

The main areas of research and action identified are:

- Scarce Resources Management
- Technologies for Sustainability
- Sustainable Lifecycle of products and production systems
- Sustainable Product and Production
- Sustainable Businesses

A.1 Technologies for Sustainability

This Research Action aim at an holistic view of product cycles in the manufacturing industry , taking into account:

- Technologies for quality, cost-effectiveness, safety and cleanliness
- Economic, ecological and social performance of product/process/service systems

Topics within the Research Action:

- **RT1.01 Quality Embedded Manufacturing**

In modern factories, smart products and machines (equipped with embedded smart devices) can be wirelessly networked and remotely monitored in a real-time way under intelligent control systems. As a result, we can do real-time data gathering; remote monitoring and analyzing of all manufacturing operations to control the quality of manufacturing, predict exceptional cases of manufacturing systems and taking appropriate actions through decision making. This provides a new environment for enhancing quality management in manufacturing.

- **RT1.14 Additive forming processes for manufacturing**

Traditional manufacturing processes are inefficient from the sustainability point of view. Additive Forming Technologies till now have been used mainly for rapid prototyping. Recently new developments start allowing metal additive forming, opening the doors to additive manufacturing of products components. The research will focus on advancing the state of the art of these technologies, understanding how can be used in manufacturing environments to improve both environmental impact and profitability.

- **RT1.20 Sustainable Data Management**

Nowadays enterprises fight the problem of inconsistent and redundant data. Although knowing about the negative impacts they are not able to avoid the appearance of these challenging effects. A sustainable management concept for data and specifying attributes is needed.

- **RT1.24 Integrative Logistics Tools for Supply Chain Improvement**
Local optimizations in the supply chain often lead to inefficiencies at other places. Therefore, tools to cooperate within a supply chain, to harmonize the logistics and improve the overall performance have to be found, implemented, and summarized in a tool box.

A. 2 Scarce Resources Management

This Research Action have a the aim of reduce the use of scarce resources through:

- Support Remanufacturing & Reuse, where there is a strong need of a reference model for material reuse optimisation
- Support Recycling, where waste materials should return in supply chain and can be used as raw materials, source of energy or to replace no renewable natural resources (minerals and fossil fuels)

Topics within the Research Action:

- **RT1.11 Material Re-use Optimization.**
The aim of this research topic is to develop methodologies and tools to improve materials reuse after products' disposal. The research should include self disassembly technologies, de-manufacture methods, technologies for composite materials, IT tools, methods and best practices to be used by large companies as well as SMEs.

- **RT1.16 Resource Recovery from Alternative Fuels and Row Materials.**
Due to increased utilization of waste materials to substitute either conventional fuels or raw materials in energy intensive industries, the recovery of trace elements contained in such material streams will become a crucial part of future manufacturing processes. Research should aim for technological solutions able to recover such trace elements in an ecological and economical way.

A.3 Sustainable Lifecycle of products and production systems

This Research Action considers Sustainability of products, processes and services all along their complete lifecycles in terms of Performance & Quality and Safety of people, facilities and infrastructures.

Topics within the Research Action:

- **RT1.03 Real-time Life Cycle Assessment**
The aim is to develop a methodology and a set of tools to allow a precise esteem of the whole lifecycle impact (LCA) and costs of a product (LCC) to be used real-time by designers during the design process. This tool will use lifecycle data information from

previous product and esteems to do a precise evaluation of the full lifecycle impact of a new product during its development as well as its full lifecycle cost.

- **RT1.06 Cost Based Product Lifecycle Management (PLM)**

Cost is the basic criteria for the product related decision making; manufacturers try to reduce the production cost, customers want to get a product in low cost, used products are differently handled depending on its estimated cost. But each participant in the product life cycle does not consider the cost from the global perspective but only from the local perspective. Hence an integrated cost management over the whole product life cycle would be beneficial for the products' ultimate value maximization.

- **RT1.13 Maintenance Concept for Sustainability**

Longer machine life cycles and higher equipment performance in respect to resource consumption, energy consumption and availability could be achieved through effective and efficient maintenance, making this topic an important issue for sustainability. New maintenance concepts should improve the level of sustainability in manufacturing through innovative and predictive measures. Therefore, new evaluation concepts integrating sustainability related aspects (e.g. Total Cost of Ownership (TCO) calculations, energy efficiency) into maintenance management need to be designed and implemented.

- **RT1.08 Predictive maintenance**

Traditionally, PLM has been based on integration of a number of centralised ICT tools (CAD, ERP, PDM, ...) predominately operated and used by manufacturers and suppliers, and hence impossible to have meaningful input by product users. With the development of distributed Closed-Loop PLM based on Embedded Information Devices that facilitates users to provide detailed and valuable information about the use stage of product, it is expected that distributed knowledge with an extended value chain demand including users/operators will be generated and used to support predictive maintenance applications for the optimal operation of an asset through its lifecycle.

A.4 Sustainable Product and Production

Modernisation of industry will be supported by this research action by improving the quality of product information and easiness of access to information at the design, production, use and end of life
Moreover Sustainable Product and Production systems will make possible to achieve a less resource intensive society and a more competitive industry.

Topics within the Research Action:

- **RT1.04 Sustainability Metrics**

The aim is to develop a scorecard for processes and a comparable "sustainability index" (Green/Sustainable Labelling) for products. The scorecard and the index have to take in account all sustainability pillars (environment, society, …) all the lifecycle phases, and information about the company and its supply chain. The scorecard will be used by decision makers to select best sustainable solutions for the companies, while the index will allow customers to understand the real impact of a product and, if they are willing, to choose competently the most sustainable product.

- **RT1.05 Sustainability workshops**

Deliver industrial driven workshops to exchange best practices and ideas on sustainability between industries and research. Some workshops have to be focused on SMEs.

- **RT1.09 Sustainable Packaging**

Packaging (primary, secondary and transit) forms an important part of wastes for both industrial and consumer goods. For this reason it is important to reduce its impact developing re-usable, biodegradable, environmental friendly or even edible packaging. The development of these issues has to take in account existing standards and regulations, finding optimizations for packaging sustainability (both ecological aspects and business aspects).

- **RT1.10 Optimization of Electronic Sustainability**

Electronic products (such as computers, IT infrastructures, TVs, etc.) could have a longer working life. Usually they are prematurely trashed because of obsolescence, not failures. Moreover these products' disposal has a high environmental impact because of the contained materials. Therefore, to reduce their impact, it is needed to develop a lifecycle comprehensive methodology to optimize the life usage of the products (re-use) as well as their disposal impact, using advanced identification (RFTags) and recycling techniques.

- **RT1.11 Materials re-use optimization**

The aim of this research topic is to develop methodologies and tools to improve materials reuse after products' disposal. The research should include self disassembly technologies, de-manufacture methods, technologies for composite materials, IT tools, methods and best practices to be used by large companies as well as SMEs.

- **RT1.21 Sustainable Supply Chain Design**

Nowadays more and more companies relocate production sites back to their original location. The reason for the failure of many outsourcing investments is the disregard of facts like skills of the workforce, transportation time and costs as well as ecological issues. Thus the development of a holistic model which is taking all relevant facts into account is necessary to enable sustainable location decisions.

- **RT 1.25 Management of hazardous substances in manufacturing**

Adequate management of hazardous substances is needed to reduce the impact of industry activity on the environment and human health and safety. Research focuses on the development of production methods, ICT solutions and recuperation technologies that reduce use and generation of hazardous substances as well as guarantee a safe

- **RT1.07 EOL management supporting technologies**

Remanufacturing is becoming more important as many countries are tightening environmental regulations or legislations in economic activities. The arrival qualities of used products are different and they even change during their remanufacturing processes. Hence, individual handling of used products depending on their dynamic quality can enhance the whole remanufacturing system performance. Optimisation of remanufacturing processes will lead to higher efficiency of remanufacturing systems that will allow for the cost effective re-use of remanufactured components while satisfying required quality specifications at the same time. This will contribute in a significant manner in the optimisation of resources usage which is one of the main objectives of sustainable manufacturing.

A.5 Sustainable Businesses

Sustainability is a challenging key business imperative, that calls for a new paradigm of thinking and acting. At the same time, it is a complex issue to manage due to the holistic nature of sustainability concept that embeds environmental, social and business aspects that are not independent of each other.
To achieve this aim enterprises, especially in SME sector, need to develop:

- business model that mediate between improving environmental performances and business competitiveness;
- methodologies and tools that support managers in decision making and in innovation process with the aim to exploit enterprise potential for sustainability;
- new approaches, workplaces, working methodologies or special training for to improve sustainable production in all its aspects.

Topics within the Research Action:

- **RT1.12 Sustainable SMEs.**
  SMEs impact is around 70% of the whole manufacturing. The aim of this research is to develop proper methodologies and business models to increase SMEs sustainability, minimizing their inefficiencies and finding a way to make sustainability a value, not a cost. The research will take in account many possibilities as, for example, the use of process modelling languages, standardization, data and procedures integration, new business and evaluation methods development.

- **RT1.17 Exploiting Disruptive Innovation for sustainability**
  Manufacturing companies need to change their approach to innovation if they want to face the current turbulent market. When developing new solutions companies need to take into account sustainability issues. The aim of this research is to develop methodologies and tools to manage and run simultaneously incremental and disruptive innovation, to exploit their potential for sustainability.

- **RT1.18 Integrated Service Supplier Development**
  Today suppliers have to provide both physical products as well as complementary services in order to meet the customer demands. Therefore, it is reasonable to build up networks in which producers and service suppliers work together on the

configuration of product-service-systems. In order to realize these networks companies need standardized methods and tools for the definition of the relevant interfaces as a common basis for an integrative development process of products and services.

- **RT1.19 Product-Service Engineering**
  Due to differentiation needs, companies face tremendous challenges to develop customer solutions as a combination of products and services. The successful application of integrated product and service engineering as a general framework is needed. A set of methodologies, tools, business models and standards for products and services, their interfaces and the underlying processes need to be developed.

- **RT1.22 Alignment of IT and business strategies**
  This research topic addresses the lack of knowledge regarding the ability to measure the benefits of IT as an indirect department. How to set up controlling and measurement standards to align IT activities to strategic company goals is the core question to be answered.

- **RT1.23 Multi-dimensional inventory management**
  Companies constantly reduce their depth of value creation leading to inherent but inefficient and ineffective increase of stock echelons in the supply chain.To overcome this, it is necessary to expand the perspective of current supply chain management to a multi-tier view by utilizing higher information flows in future. New multi-stage models for supply chain configuration defining stock keeping echelons and order penetration points to optimize supply chain inventory levels are undisputed required.

- **RT 1.26 Lean Management for Service Industries**
  Whereas the business world is constantly changing from a manufacturing into a service dominated world, service management still suffers from significant drawbacks in approaches for an efficient and effective service production. Lean management has considerable changed manufacturing industries and seems to be a promising approach for service industries too. Therefore implementation approaches as well as service-oriented lean management methodologies and tools have to be developed**.**

- **RT1.15 New workplaces for Aging and Disabled Workers**
  In the aging society also workers in manufacturing companies are affected. Moreover disabled people' integration is starting to be an important issue. Considering these social aspects companies have to renew the work processes. For this reason new approaches have to be developed using new tools (design for all), workplaces, working methodologies or special training.

B. Energy Efficient Manufacturing

There are four major areas for research and action:
- Energy Sources for Factories
- Efficient Production Processes
- Energy Utilization in Collaborative Frameworks
- Management and Control of Energy Consumption

B.1 Energy Sources for Factories

The rise of energy prices, the risk of unavailability, and customers' environmental awareness lead to the need of adapting the sourcing strategy to become independent on the one hand and to maximize the use of available energy within the factory on the other hand.

Topics within the Research Action:

- **RT 2.04: Energy Autonomous Factory**
  In order to reduce energy consumption and to guarantee a reliable energy supply, technologies and frameworks have to be developed for production-sites, which enable self-dependent energy generation according to the actual on-site demand and facilitate the use of renewable energy sources.

- **RT 2.03: Using Energy Harvesting for Powering Electrical Sensors and Devices in Manufacturing Processes**
  Energy harvesting is a concept to transform surrounding energy (e.g. thermal, kinetic, waves) to electrical energy. By finding potentials and developing solutions for manufacturing, e.g. sensors' and controllers' energy storage devices can become smaller or even dispensable.

B.2 Efficient Production Processes

The research within this actions aims at reducing energy consumption whilst increasing the output. With this a key issue is approached as each kW of energy saved results in much larger amounts saved in energy "generation" (due to losses from plant to consumer).

Topics within the Research Action:

- **RT 2.10: Energy Efficient Particle Size Reduction**
  Current grinding processes have very poor energy efficiency, as only few percents of power are used for breaking chemical bonds of materials. New grinding concepts and technologies have to be defined (e.g. pre-treatments, flexible grinding systems) and demonstrated.

- **RT 2.11: Green Manufacturing for Future Vehicles**
  Taking into account the interdependencies of product design and the manufacturing process, new possibilities of car-manufacturing due to new product architecture of "green cars" (e.g. hybrid, electrical cars) should be analyzed and new energy efficient production concepts developed.

- **RT 2.09: Emission Reduction Technologies**
  Resource and energy intensive industries emit substantial amounts of green house gases and other polluting substances. Secondary emission reduction technologies have to be developed in a coordinated approach across sectors. With this, benefits from implementing similar reduction and capture technologies in different industries can be expected.

B.3 Energy Utilization in Collaborative Frameworks

Dissipating energy in form of heat or by products is in many cases taken as waste output. However, an economically viable reuse is often possible in another production process or industrial sector. For this reason this Research Action will promote the improvement of effective use of available energy by enabling collaboration.

Topics within the Research Action:

- **RT 2.07: Technological Access to Wastes for Enhanced Utilization**
  Enhanced utilization of alternative fuels and raw materials, derived from waste, replaces natural resources and as such reduces the environmental impact of resource intensive industries. Technological advances in pre-treatment and upgrade options are required. Adaptation of the main existing processes needs to be demonstrated in a cross-industry approach.

- **RT 2.05: Intelligent Utilization of Waste Heat**
  Factories in process industries are point sources of low and medium temperature waste heat, which remain widely unused representing environmental and economic opportunities. Expected outcomes are a methodology for cross-plant analysis of waste heat recovery potentials, recovery technologies and demonstrated co-operations between industries/plants for optimized utilization of heat at various temperature levels including low temperature waste heat.

- **RT 2.06: Framework for Collaboration in the Alternative Fuel and Raw Material Market**
  Resource intensive industries significantly contribute to green house gas emissions making it an important sector for mitigation actions. Here, waste/by-products can be used to replace raw material and fossil fuels in industrial processes. Methodologies and strategies for cross-industry and cross-sector collaboration have to be developed in order to enable increased utilization of waste.

B.4 Management and Control of Energy Consumption

Manufacturing systems have to be enhanced to fit today's energy oriented requirements. This Research Action aims at achieving a better understanding, management and control of energy consumption as basis for further improvement measures.

Topics within the Research Action:

- **RT 2.01: Energy-Aware Manufacturing Processes - Measurement & Control**
  An effective energy control system has to be developed, using the information of sensors and in-process measurement and a suitable energy efficiency performance measuring system. This control system focuses on concepts, which facilitate the evaluation, control and improvement of energy efficiency in manufacturing processes.

- **RT 2.02: Integrating Energy Efficiency in Production Information Systems**
  A novel framework that manages and optimizes energy efficiency with respect to production planning and control needs to be developed and implemented in enterprise control and information systems, such as Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), and Distributed Control Systems (DCS).

- **RT 2.08: Product Tags for Holistic Value Chain improvements**
  Product related information about the in and outputs of manufacturing processes make the value chain transparent for its stakeholders. The transparency allows process improvements to be coordinated in order to increase the overall value chain performance (in terms of e.g. efficiency, costs, delivery time).

C. Key Technologies

Four areas are proposed for that research:

- Flexible Manufacturing Systems
- Cost-Saving Manufacturing Systems
- Energy-Saving Manufacturing Systems
- Key Technologies embedded in manufactured products

C.1 Flexible Manufacturing Systems

Manufacturing industries need to be able to adapt quickly to market challenges and to take advantage from market changes, and the new possibilities offered by sustainability. Flexible production systems may mitigate the effect of demand uncertainties.

“Mass customization” and “build-to-order” manufacturing paradigms, are more and more important, so to face this technological challenge, the manufacturing companies need machines and manufacturing systems that are productive and reliable and that at the same time are highly flexible and adaptive both in terms of volume and variants of the manufactured products.

To achieve this, the manufacturing sector needs a multi-disciplinary approach for conceiving and manufacturing flexible and adaptive manufacturing systems by covering the different stages of their life-cycle, from design and assembly to use and end-of-life.

Topics within the Research Action:

- **RT3.02 : Control for Adaptability**
  In manufacturing process it is essential to integrate process models in the control system that allows optimal performance under different conditions. New control systems could overcome the limits of traditional systems and be able to react in time to fluctuations during the process, to changes of process parameters and disturbance variables.

- **RT3.03 : Mutable Production Systems**
  Short delivery times and the increasing complexity and variety of manufactured products are demanding more than highly flexible production systems. Furthermore production systems need to be changeable enabling the reconfiguration to adapt to changed conditions in a fast an efficient way.

- **RT3.08 : Model Based Engineering and Sustainability**
  The engineering of customised manufacturing systems involves an integrated model-based approach that covers products+services, processes and business models in an integrated way.

- **RT3.09 : Cooperative & Mobile Manufacturing Systems**
  An innovative way for conceiving flexible production plants lies in re-conceiving those production plants as dynamic communities of mobile robots capable of cooperating among them and with human workers.

- **RT3.12 : Mechanical Micro Machining Enhancement**
  The miniaturization of machine components is unanimously a key issue for the future technological development. However, numerous technological problems prevent the adoption of micro-manufacturing technologies at the industrial level. Cost effective and reliable mechanical micromachining processes must be developed through a deep comprehension of the material removal mechanisms and of the micro structural behaviour of materials and its effects on machining forces, deformations and quality on the work piece. New concepts are also needed for fixturing and handling systems, modular and multifunctional machine tools, process monitoring and control through accurate sensors and methods of data analysis.

- **RT3.19 : Forthcoming "Brown Fields" Re-Engineering**
  The scope of this research is the development of a new business model to increase the effectiveness of brown field production. Therefore it is essential to develop supporting tools and methodologies such as, for example, “plug and interoperate” devices, interfaces for interoperability, fast simulations and re-programming tools, methods to improve the plant control, assembly and disassembly aspects.

- **RT3.16 : Extracting Higher Potential from Regional Cluster Based on Professional Virtual Collaboration Platforms**
  For the manufacturing industry it is imperative to continue to exploit innovative business strategies long time in advanced. One essential strategy of the future is to participate in dynamic business networks. Two major objectives of this strategy are to bring the core capabilities into a flexible network and to govern through stakeholders. The result should be dynamic and flexible representation of business processes and technology for virtual collaboration among regional clusters. Therefore, the research focus should be on extracting higher potential from regional cluster based on professional virtual collaboration platforms (collective governance and expert contribution).

- **RT3.17 : Ontology Based Engineering Asset Management**
  The main goal of Product Lifecycle Management (PLM) is the management of all the business processes distributed along the product’s lifecycle phases. These phases are BOL (Beginning-Of-Life including design and production), MOL (Middle-Of-Life including logistics, usage, maintenance and service) and EOL (End-Of-Life including reverse logistics, recovery, disassemble, remanufacturing, reuse, recycle and disposal). A major requirement for efficient PLM is the traceability of the product which is the acquirement of information along the product’s lifecycle about the product. Although the volume of information may be manageable at the beginning of product lifecycle, it will rapidly grow as product lifecycle becomes evolving. This generates a comprehensive genealogy of product lifecycle meta-data, which causes difficulty in managing and retrieving the data or information that we need. Information can be used to extract knowledge, to improve features of products and of future products. A big amount of this information-knowledge is being lost, due to lack of reasoning capabilities as well as lack of interoperability and integration of information of today’s PLM systems and models.

C.2 Cost-Saving Manufacturing Systems

In the current industrial environment, anyway, companies need to reconsider their production systems and processes within a life-cycle view, aiming at conceiving, designing, producing and using cost-effective, value-adding and sustainable manufacturing systems as basis for minimising total life-cycle costs associated to manufacturing and logistics systems.

Both physical and organizational processes must be able to achieve higher performances to quickly respond to technical and cost constraints due to environmental, economic and societal issues. Manufacturing should optimise total life-cycle cost of manufacturing systems, including logistic costs, shortening lead time of material & information, improving added-value and service levels for end-users.

Topics within the Research Action:

- **RT3.04 : Lower Labour and Energy Cost Performance**
  COST linked to SUSTAINABILITY is the main driver of this research topic. Cost issues are fundamental in the manufacturing industry and when addressing them, two main aspects come in front: the labour cost and the energy cost, which are linked to environmental sustainability and to aspects of human safety at work. This research topic addresses both issues in a combined way: the efficiency, effectiveness and safety of work force (people) involved in manufacturing activities, and the optimised utilisation of energy streams with a low energy consumption level.

- **RT3.05 : Interoperable Products and Production data exchange**
  Companies can be part of several production networks at the same time thus making the planning, management and optimisation of these networks a very complex task. This requests collaborative planning, management and optimisation of production and logistic resources, including the production planning and capacity management in non-hierarchical company networks. These processes have to be standardised across industries in order to come up with the necessary speed and flexibility in the network integration.

- **RT3.13 : High Resolution Total Supply Chain**
  To keep production units in high-wage countries, companies have to concentrate on manufacturing complex and individualized products. Being able to adapt processes according to supply chain requirements is a key success factor. Decentralized self optimizing control mechanisms, based on a new level of information transparency and synchronized target systems are indispensible. Therefore a multistage control loop system of intelligent objects based on cybernetic models has to be developed.

- **RT3.06 : Build-to-Order - New Production Planning and Control Models for Complex Individualized Products**
  The production of complex products requires the involvement of different partners providing services, materials or manufacturing activities. The demand of individualized products asks these non-hierarchical organizations the ability to quickly respond to customers with high service levels and low overall costs. New production planning and control approaches must be developed to coordinate the production activities and to assure robust production performance against uncertain events and against the propagation of production plan disruptions within the network enterprise.

- **RT3.10 : High Performance (High Precision, High Speed, Zero Defect)**
  To increase efficiency of manufacturing system, this topic covers productivity gains and cost saving to face market changes and eco- society sustainability issues. The aim of this topic is to increase the capability of manufacturing systems to maintain highest standards in the event of frequently changing operating and product-mix conditions. To provide more efficient and productive outputs, technologies for high volume, high speed and new capabilities of processes are needed.

- **RT3.11 : Model-based Manufacturing**
  Model-based manufacturing refers to the development of virtual manufacturing environments that will allow explicitly integrating knowledge in the manufacturing chain. Expected outcomes are tools for manufacturing environment simulation and information exchange with other production stages.

- **RT3.18 : Semantic Based Engineering**
  Although a lot of data is being collected by various systems, there is no efficient and productive method to process the data. The development of Systems capable of generating knowledge is required. These systems will be concept-based and will combine concepts with data to generate new knowledge.

- **RT3.14 : High Accuracy Modelling**
  Companies face the problem that current planning approaches aren't able to incorporate all relevant influence factors leading to inefficient and ineffective production in worldwide networks. Integrated multiple optimization of economic and sustainable production based on high resolution modelling seem to be a reasonable solution. There is a need for development of methodologies and new ways of visualization based on ICT. This would improve planning and forecasting of processes within complex company networks involving multiple stakeholders.

- **RT3.15 : Semantic Business Processes**
  The intensive global competition motivates an increasing number of companies to cooperate throughout the entire value chain. Models, tools and standards for inter- and intra-organizational business workflows and process execution have to be developed in order to guarantee high-quality integration of processes within cooperation. Using semantic descriptions for this purpose ensures flexibility and a common understanding of involved processes.

- **RT3.23 : Dealing with unpredictability**
  Innovation processes are crucial in developing products and processes in manufacturing companies. Traditional methods are insufficient to cope with the risk embedded in such projects and radically new methods are needed taking both contextual and strategic risk into account. The impact of this topic will be better predictability of innovation projects. It will develop a new attitude towards delaying with risk in manufacturing projects.

C.3 Energy saving Manufacturing Systems

Builders and users of manufacturing systems demand innovative solutions (manufacturing systems + services + processes) with reduced consumption of energy and material resources. This enables a competitive position and a sustainable development of the manufacturing sector that needs solutions ensuring quality rates of manufacturing systems while reducing energy and material resources. This target means introducing new parameters for energy efficiency and raw-material efficiency. A paradigm shift will be necessary in the current design approaches of manufacturing processes towards new conceptual approaches that relate specific energy and materials savings to manufacturing, taking into account the whole life cycle and the ecological, as well as societal impact of the manufacturing systems.

Topics within the Research Action:

- **RT3.07 : Efficient Use of Raw Materials**
  In manufacturing, using raw materials efficiently directly saves costs and energy in transformation, transportation, and disposal and, with this, reduces Green House Gas Emissions. By focusing on “zero-waste” and “zero-defect” technology developments, the amount of energy and resources required in manufacturing can be reduced as it is linked to the amount of material processed in the whole supply chain.
- **RT3.20 : Advanced Automation for Demanding Process Conditions**
  Advanced automation and control systems for process industries with fluctuating input streams (such as raw materials, fuels, etc.) need to be developed. The aim is to increase process stability. Besides of a constant product quality, energy consumption and production costs can be reduced by achieving higher throughputs and increased energy efficiency of the process.

C.4 Key Technologies Embedded in the manufactured Products

The manufacturing industry needs to shift from providing technologically advanced products to providing total solutions, i.e. products + services + processes, to increase the value perceived by customers. Within this view, manufacturers will have to focus on solution thinking and besides will have to integrate their potential customers in the development process of those innovative solutions as a means for generating new business opportunities and for creating more value for their customers.

This has to leverage on intelligent products and customised services for allowing customers obtain the maximum value and innovative customer-oriented services.

Topics within the Research Action:

- **RT3.21 : Business concept B2C-communities**
  The increasing competitive pressure on global markets constrains companies to reduce their costs and to encourage customer retention. By integrating customers into the development process of new products and services, companies are able to

save money and to meet end customers' requirements. Therefore methods, tools and standards are needed that help companies to build up their individual B2C-communities.

- **RT3.22 : Knowledge Embedded Products**
  More intelligent products with embedded knowledge, use of smart materials, sensors, RFID etc will generate new business opportunities and competitiveness for the manufacturing industry and more value for the customers. Through case studies of best practice and state-of-the art within knowledge embedded products, the manufacturing industry will obtain new innovative ideas on how to provide more value for their customers. For the manufacturing industry this will not only represent new markets but also more value and sales to existing customers.

D Innovation, competence development and education

The Research Topics are described below.

- **RT5.01 : Teaching Factories**
  Teaching factories are real production facilities developed for education and training purposes for students and workers, which will significantly reduce the gap between academia preparation and industrial needs, and improve the life long learning effectiveness of skilled workers.

- **RT5.02 : Cross Sectoral Education**
  The manufacturing industry is in constant need for updating their competence across many disciplines as new enabling technologies and global (cultural and societal) development constantly provide new opportunities and challenges. There is a serious need for research to understand how professionals and enterprises can most efficiently acquire such cross sectoral competence on a continuous basis, particularly in SMEs where individuals often need to stay up-to-date in many disciplines.

- **RT5.03 : Communities of Practice**
  The understanding of the important processes in which individuals develop, use and communicate innovative and dynamic knowledge, outside of the traditional knowledge management systems, is immature. Communities of practice can provide more structure to these knowledge exchange processes within and across organizations, there is a need to better understand how these processes and methods may be established and maintained to make exchange of best practice efficient and sustainable.

- **RT5.04 : From tacit to explicit knowledge**
  Individuals' tacit knowledge is a crucial component of the enterprises' knowledge base, however, traditional knowledge management systems are not suitable for capturing and externalizing tacit knowledge, a problem particularly critical to SMEs which are vulnerable to loss of core competence when individuals leave the company. Research into how emerging technologies (unstructured tagging,

weblogs, wikis, etc.) may help capture tacit knowledge, in conjunction with understanding how this knowledge may be socialized, e.g., through communities of practice, may help companies to better utilize tacit knowledge.

- **RT5.05 : Innovation Agents**
  Global innovation agents represent actions in finding and developing innovation and ideas globally, and implementing the new ideas to the manufacturing industry, making sure that innovation and research in the manufacturing industry represent the latest and most innovative areas. Research within this area needs to focus on innovation agents as a concept for learning, and how this may be implemented in the manufacturing industry, e.g., through the identification of state-of-the-art and empirical evidence.

- **RT5.06 : Benchmarking**
  Benchmarking as a tool is well established, but still lacks refinement to present a powerful mechanism for learning, however, benchmarking has a clear potential as a systematic learning methodology. The proposed research will investigate how benchmarking can be converted into a systematic approach for learning, identify the necessary infrastructure to attain this, as well as undertake pilot implementations to evaluate the effects.

- **RT5.07 : Serious Games**
  In the knowledge society, human capital has become of strategic importance for enterprises and there is a need for more effective technologies and methodologies to support rapid competence development, knowledge externalization and knowledge transfer. The use of serious games for game-based learning empowers enterprises with greater agility in responding to market pressures and needs.

- **RT5.08 : Personalized and ubiquitous Learning**
  Flexible and targeted training of individuals, permitting individuals to choose when and where to learn, is preferable when individuals are required to stay up-to-date in their fields when faced with tight schedules and high workload. Digitalized course module repositories for manufacturing, supported by tutoring systems can be developed and adapted to mobile technology to allow tailored and individualized learning paths, made available through the use of, e.g., mobile technology.

- **RT5.09 : Accelerated Learning**
  Systematic learning from experiences and from exploring new ideas, through Problem Based Learning, has a great potential for enabling faster and better take-up of new technology, products and services in the manufacturing industry. Research needs to focus on two parallel activities, i.e., the development of a problem based learning approach enabling training of employees, experience exchange and cooperation within and between organizations, and the development of inter-company exchange programs for stimulating collaborative learning.

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