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PROJECT FINAL REPORT

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Project acronym: EMC2-Factory

Project title: Eco Manufactured transportation means from Clean and Competitive Factory

Funding Scheme: Collaborative project

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4. 1. Final publishable summary report

Executive summary

According to the International Energy Agency, manufacturing is responsible for approximately 37% of global primary energy consumption being the largest energy consumer and CO2 producer. Improvement of energy/resource efficiency is the key to reduce environmental impact and is mentioned as driver to achieve European 20/20/20 goal. Hence, European manufacturers have to rethink their current ideas about design and management of manufacturing systems, to take a significant step towards the new resource/energy efficient, sustainable factories.

EMC2-Factory project aimed at enabling European manufacturing industries to overachieve Europe 2020 program targets through development of a breakthrough paradigm for cost-effective, highly productive, energy-efficient and sustainable production systems, through:

- Definition of a holistic perspective of the economically and ecologically oriented factory;
- Development and evaluation of new enabling technologies to guarantee resource usage and emission reduction in manufacturing systems;
- Development and extension of new factory design, planning and optimization tools to improve energy/resource efficiency, exploiting building-production equipment interaction;
- Provision of integration reference models and guidelines to support the shift towards new sustainable production;
- Definition of standards for economically and environmentally sound factories.

EMC2-Factory has improved and developed new technologies and processes, combining existing tools and methods in an overall integrated framework, to achieve economic and ecologic factories. It focusses on main energy intensive processes within the most relevant industrial sectors in Europe (automotive, rail and aerospace), developing tangible and industry relevant results to be easily implemented in cross-sectoral manufacturing environments. To assure the impact on European economy, EMC2-Factory partnership includes main industrial players (as well as SMEs) in manufacturing, highly-recognized research centers and universities and one of the main European industrial associations. The project results are therefore leading to a sustainable, as well as economically profitable, green factory framework. The new established paradigm will become a permanent reference point in European Manufacturing.

Project context and objectives

According to the International Energy Agency, manufacturing is responsible for approximately 37% of global primary energy consumption being the largest energy consumer and CO2 producer. Improvement of energy/resource efficiency is the key to reduce environmental impact and is mentioned as driver to achieve European 20/20/20 goal. Hence, European manufacturers have to rethink their current ideas about design and management of manufacturing systems, to take a significant step towards the new resource/energy efficient, sustainable factories.

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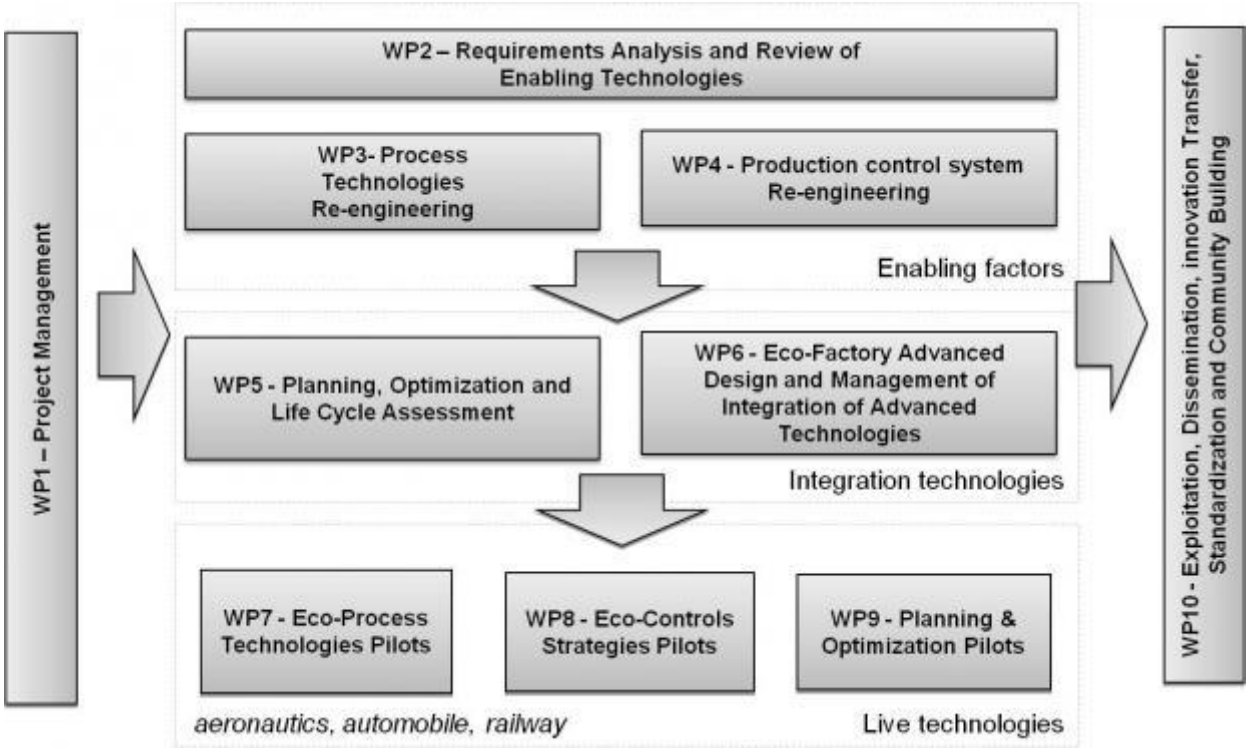
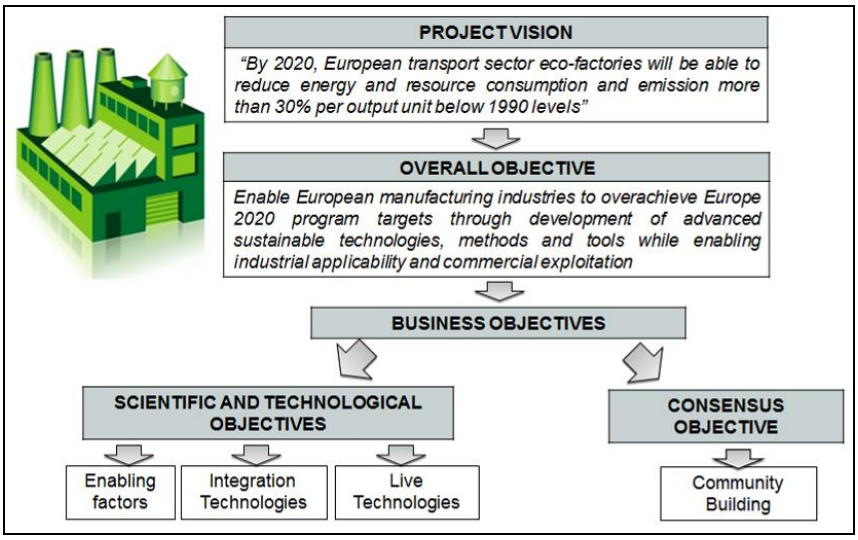
In order to successfully reach the main objectives of EMC2-Factory, 10 Work Packages (WPs) have been identified as main building blocks of the project. Each WP has specific objectives and is critical to reach the overall target of EMC2-Factory. The relations among the different WPs is presented in the figure below:



WP 1 covers the overall project administration, in terms of planning and controlling infrastructure. WP 2 addresses the requirements analysis and review of enabling technologies, and it represents the foundation of the project. In fact, this WP generates and presents the sound knowledge on top of which advances in research and development are built. Since EMC2-Factory will use the latest technologies in an integrated approach aiming at the future Eco-Factory, a thorough investigation of Best Available Technologies (BAT) is also performed in this WP. WPs 3, 4, 5 are three parallel

streams of research and development that focus on the main drivers affecting eco-performances in a factory: process technology, process control, production management and optimization. In WP 3 the re-engineering of process technologies is addressed: existing process technologies are evaluated and improved in terms of their eco-efficiency performance. The focus of WP 4 is control systems for production environment, investigating controls, sensing and actuating technologies in order to improve eco-efficient as well as resource efficient operation through enhanced real-time control of machines, cells, lines. Finally WP 5 looks at the management of resources (machines, buildings, people, etc.) in order to improve eco-impact of factories through appropriate planning and control of activities, given the required production. While WPs 3, 4, 5 focus on different technology developments, WP 6 investigates the integrated adoption of these technologies in a holistic approach. Hence it investigates at factory level how to use, with an integrated approach, different techniques to go towards the envisioned Eco-Factory, e.g. exploiting availability of information about resources consumption, different eco-efficient process technology solutions, as well as enhanced eco-efficient management of resources. Then three demonstration WPs (7, 8, 9) address the implementation of the concept developed in the project into three different sectors, Aerospace [Aciturri], Automotive [COMAU], Rail [Siemens]. Finally WP 10 addresses all the activities that support the exploitation and dissemination of project results to the scientific and industrial society. Among these activities there are: Dissemination, Exploitation, and Innovation Transfer. Using the output of all other WPs, WP 10 will publicly present the project results, using the most appropriate approaches (publication, exhibition, etc.). All these activities are necessary in order to support and reinforce the impact of the project results on the society, considering both industry and academy (European Hub on Sustainable Manufacturing).



PROJECT'S VISION: *By 2020, European transport sector eco-factories will be able to reduce energy and resource-consumption and emission more than 30% per output unit below 1990 levels.*
Starting from the vision, it is clear that research effort is required in order to provide manufacturing companies with advanced tools and sustainable technologies to go towards future eco-factories. Hence, the overall objectives of the EMC2-Factory project are defined as follows.

OVERALL OBJECTIVE: *Enable European manufacturing industries to overachieve Europe 2020 program targets through development of advanced sustainable technologies, methods and tools while enabling industrial applicability and commercial exploitation.*
From this overall target, an integrated set of objectives are derived, with respect of Businesses (Business Objectives), Science and Technology (Scientific and Technological Objectives), and Consensus building (Consensus Objectives).

BUSINESS OBJECTIVES:

- *To increase production systems profitability and allow access to new markets through improvements in energy efficiency emission and cost effectiveness;*
- *To realize economically and ecologically sound processes which are able to move into new markets and product areas rapidly;*
- *To realize more knowledge-intensive processes which are based on the wide diffusion and re-use of eco-solutions;*
- *To realize more robust businesses through eco-solutions which are scalable and recoverable;*
- *To realize more valuable businesses from a long term and more general perspective.*

From the perspective of the overall program, the fulfilment of the scientific and technological objectives and the consensus objective are the means to achieving the business objectives.

TECHNOLOGICAL OBJECTIVES:

- *To define an enabling technology reference model that provides resource and emission reduction foundation for specific process innovations;*
- *To provide integration technology reference model solutions which enable and support the above;*
- *To provide appropriate factory design tools and methods towards more energy and resource efficiency which enterprises can use to manage organisational roles, skills, competencies, and knowledge assets for its own operation and for collaboration with other enterprises;*
- *To define economically and ecologically oriented requirements for processes, equipment and management strategies and provide system solutions, using the above technologies, that meet these requirements;*
- *To provide standards for economically and ecologically sound factory infrastructures.*

In order to generate optimal impact, required for the fulfilment of the business objectives, the results of the EMC2-Factory initiative need to reach as many end users, researchers, technology providers and other stakeholders as possible who constitute the broad manufacturing community. The EMC2-Factory initiative's main Consensus objective is to gain the support of a critical mass of the European manufacturing community.

CONSENSUS OBJECTIVE: *Establish a permanent World-Class European Hub on Sustainable Manufacturing acting as a reference point in Eco-Factories issues to be recognized by research and industry community.*

- Contribute to establish Eco-labelled process standards to support European policy.

Main S&T results/foregrounds

WP2 - Requirements Analysis and Review of Enabling Technologies

The main objective of this work package was to define the requirements for a greener and more resource efficient production system taking into account the different industrial environments of the manufacturing partners within the consortium. The analysis of the functional requirements of the technical production environments taken into consideration ensures the definition of main requirements and specifications for the eco-factory. This analysis includes the following tasks:

- the analysis of functional requirements for new clean and resource-efficient production (Task 2.1);
- the analysis of technical production environments (Task 2.2);

- the review, evaluation (through appropriate Key Performance Indicators), and selection of best existing technologies to fulfill the defined functional requirements and to ensure their applicability (Task 2.3);
- a holistic vision for the future eco-factory which serves as a reference (Task 2.4).

WP3 - Process Technologies Re-engineering

WP3 main purpose was the selection and evaluation of Process technologies for all considered process domains and for all considered sectors. Within this WP the following topics have been investigated and developed:

- Machining MQL process. Different MQL lubricants have been tested in order to identify the better oil to improve tool wear resistance on materials;
- Machining alternative process cooling systems for tool wear resistance improvement;
- Optimization and increasing machining efficiency (Eco Efficient Machine Center), with development of measures to reduce energy consumption;
- New solutions to improve energy savings in compressed air system;
- Alternative joining technologies based on FSW for rail and optimization of laser for automotive applications;
- Optimized resistance spot welding gun with compact solution for automotive application;
- Remote laser welding process optimization with process line impact evaluation for extension to Body side application on production line environment.

Significant results

- Evaluation of applicable alternative joining technologies to those currently used by industrial partners;
- Definition of design of experiments aimed at preliminarily assessing the suitability of alternative technologies;
- Protocols for the calculation of energy consumption of joining processes;
- Strategies implemented for the definition of a methodology suitable to compare energy consumption between investigated processes;
- Remote laser welding process optimisation - process parameters have been identified for the most relevant joint configurations, both in 2 and 3 layer configurations.

WP4 - Production Control Systems Re-engineering

Work package 4 is dedicated to the re-engineering of the production control systems which aim is to manage the eco-efficient technologies developed under WP3. The resulting systems are intended to be used to control the technologies that are installed in the project's demonstrators. Two main steps have been performed:

• an evaluation of the technologies available on the market, with the aim to identify inefficiency and possible areas of improvement and development;

• deep analysis to perform a step forward in order to re-engineer the present control architectures, to make it strongly oriented to the efficient control of energy and wastes as well as the performances of the production plant.

Significant results

Task 4.1 Efficient actuation systems

Assessment Tool for Actuation Technology:

- Algorithm for approximation of energy consumption (as total costs) of hydraulic, electric and pneumatic components, units and/or systems
- Comparison and break-even point calculation for different system configurations

Energy-efficient operation strategies for drive systems:

- Pneumatics: Novel valve cluster supporting flexibility for application-specific actuation concept, e.g. reduced pressure at end position, or load-adaptive fill-up of cylinder
- Electrics: Improved hardware as well as energy-optimized motion profiles

Task 4.2 Machine modeling & control

Energy-exact machine modelling for improved technology assessment:

- A software tool (demonstrator) that can evaluate the energy consumption of production machines by the use of simulation models

Performance-Optimized Machine Control on Machine Level:

- Energy-based control strategy that increases energy efficiency by keeping the machine tool in low energy states when production is not requested.

Performance-optimized machine control on plant level:

- Model Predictive Control technique that is able to manage control problems characterized by constraints both on the control actions and on the process variables by optimizing a performance formula.

Shopfloor scheduling with focus on resource efficiency:

- Multi criteria schedule generation framework
- Software that automatically generates a set of non-dominated solutions to the scheduling problem

Task 4.3 Intelligent Sensing and Monitoring

Monitoring Concept - Pneumatic Module

- Applicability case study
- Efficiency procedure costs and reference installation
- Prototype station with laboratory module implementation
- Prototype demonstration of smart energy shut down strategies within laboratory environment
- Setup of a mobile carrier to utilize the smart pneumatic monitor in multiple fields of application
- Development of a user visualisation (HMI) for quick analysis and evaluation of effects on energy efficiency

Lean & Green monitoring in production set-ups

- Simple recommendation for suitable industrial energy sensing technology to acquire KPIs for transformation processes
- Description of technical characteristics to ease up the implementation of sensing technology
- Quick changes in production plan and process parameters can be applied and benchmarked dynamically with lean & green KPIs
- Applicability and interpretation effects on KPIs for process chain as well as single process or component level can be demonstrated
- Hardware prototype with 3 process steps is set up. Software visualization is currently developed

Smart Valve Terminal

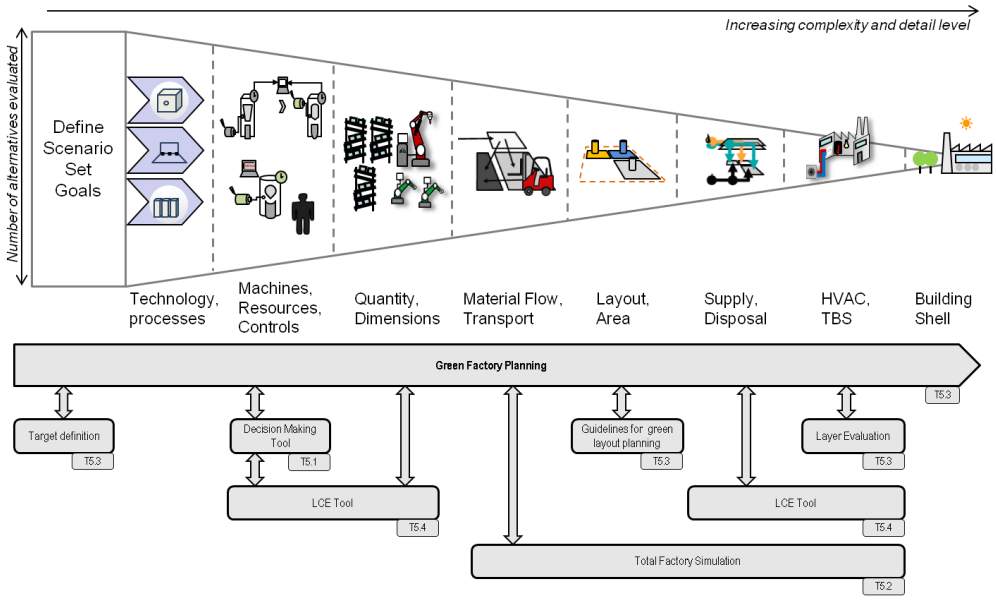
- Concept for a lab-scale solution using a simple and already existing valve terminal adding a flow sensor and a control strategy on the PLC to become able to monitor leakages

Dynamic monitoring of Machine

- Concept for monitoring the dynamic performance of machine and machining operations
- study of appropriate sensors

WP5 - Planning, Optimization and Life Cycle Evaluation

The main aim of WP5 was to develop or update methods and tools to support planning and evaluation of clean and competitive factory, considering both brownfield and greenfield projects.
Factory planning is understood for the purposed of this document as a design process that takes product and location of the factory as defined inputs and supports the decisions on processes, resources, material flow, layout, building and building services in order to finally come up with a detailed plan for a new or renewed factory. To achieve this, the planners have to follow a logical flow of decisions.
Adding the environmental perspective to factory planning increases complexity, effort for data gathering and analysis as well as lacks of transparency in decision making; all this in context in which planning resources (time, cost, and people) are limited due to market pressure. Therefore, the planner has to focus its activities on the most relevant planning tasks for eco-efficiency, increase transparency about environmental issues in the planning activities and create evaluation bases to achieve clearly set targets.
For this reasons supporting methods and tools were developed and they are presented as overview in the following figure that shows the logical process of factory planning based on a given product and location (as said both out of scope for this research project).
The figure does not represent a strict sequential process that should be followed, but the logical process for factory planning. Along with the definition of details of the factory to be planned, the number of alternatives that are considered for the evaluation reduces; hence when at the beginning several alternatives are evaluated at strategic level, towards the end usually one or maximum two alternatives are evaluated at detailed level.



Overview of methods and tools developed within WP5

Significant results
The main results can be summarised as follows:

- A method called Green Factory Planning has been defined within Task 5.3. This method supports the whole factory planning process by helping the planner following all steps needed to plan factories, in which building and processes are considered together for achieving maximum energy and resource efficiency. It includes as a first key step a prioritization phase in which the most relevant activities that should be done to achieve resource efficiency are defined based on the specific factory project addressed.
- As initial tool to support the decision making when buying a machine, a so-called "decision making tool" (developed in Task 5.1) has been developed. This tool helps the user in quickly estimate energy consumptions, related costs and possible savings on machine and line level.
- Development of a framework and tool for lifecycle evaluation (LCE) of machines/factories (activity performed within Task 5.4). While the framework defines the key life cycle phases to be considered for a factory, the related tool supports the evaluation from the economic, environmental and social impacts of factories and their components along the life cycle phases.
- Guidelines for defining layouts have been developed, as well as a concept for evaluating layout through alternatives layers that show production as well as energy and resource related performance.
- A simulation environment that combines different approaches (developed within Task 5.2) has been developed. This is a tool for detailed simulation and analysis of planning alternatives, in order to support optimization of energy/resource efficiency combining typical production with building simulation solutions.

WP6 - Eco-Factory Advanced Design and Management by Integration of Advanced Technologies

WP6 has collected the results of WP2, WP3, WP4, and WP5, organized them in a consistent framework and delivered them directly to WP7, WP8 and WP9 to enable a successful implementation on pilots.
The work plan of WP6 was based on 6 working groups:

- WG 6.1 - Lean & Green Factory Vision and Guidelines
- WG 6.2 - Eco-Controls Simulation Tools
- WG 6.3 - Smart Controls and Energy Recovery Options
- WG 6.4 - Lean & Green KPI Monitoring
- WG 6.5 - Energy sensing, assessment and monitoring
- WG 6.6 - Standardization

WG 6.1 has prepared a preliminary guideline format based on a tree diagram with a clear industrial relevance and applicability. The activity related to smart controls, simulation and energy recovery includes the following main topics: overview and classification of the simulation tools developed within EMC²-Factory; verification of results and simulation tools in case-studies defined in DEM WPs and in lab environment; study and implementation of advanced control solutions at component, machine, line and system level within the overall concept of lean and green factory. Energy recovery techniques were a key enabling factor to achieve significant results in terms of environmental sustainability. WP6 activity has develop an assessment strategy for energy and emission sensing in factory environments (brownfield /greenfield); monitoring strategy for seamless integration of energy sensors, communication infrastructure and visualization hardware on all levels of a production system; generic modules and guidelines for dynamic eco-KPI visualization

on factory, process chain and unit process level. WP6 has also developed a mobile multi sensor system for energy and emission measurement on targeting e.g. quick energy value stream analysis campaigns in production environments. The standardization activity aimed at providing compliance between the project results and national or international regulations related to environmental issues in manufacturing, in order to support industry with norms. The outcome of the activity is a full identification of relevant existing norms applicable to environmentally friendly manufacturing, and the definition of potential areas for future standards.

Significant results

- survey of all existing standards and legislation relevant to environmental sustainability in manufacturing processes
- description of formal "Lean & Green" model and its application
- set of 28 guidelines developed during the project, in a standard template with all information needed for effective industrial application, at different factory levels and in different manufacturing environments
- list of 54 energy related KPIs for assessing the eco-performances of manufacturing systems, with a detailed indication of physical dimension, application level and addressed function
- Experimental setups and simulation tools for energy efficiency monitoring.

WP7 - Aeronautics industry pilot

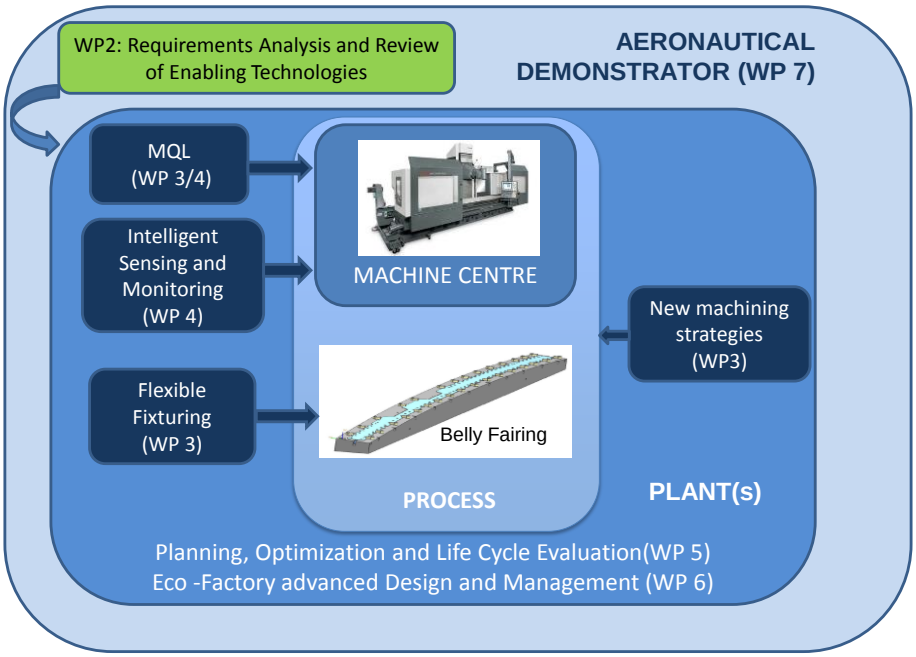
WP7 is the first of three sectors oriented work packages that evaluates the concepts, methods and technologies developed under WPs 2-6 in the Aeronautics sector. It demonstrates how the project provides valid solutions widely applicable at industrial level to design, build, and operate manufacturing plants, meeting the strictest requirements in terms of energy consumption, monitoring and control, energy recovery, and advanced systems optimization.

The pilot activities are divided in two iterative steps: laboratory and industrial environment conditions. In the first step, the WP has tested and evaluated the new technological solutions through prototyping in a lab setup. The final validation has been subsequently carried over a real pilot related shop floor.

This Work Package aims to demonstrate the effectiveness of the developed eco-process technologies by executing demonstration activities in the Aerospace pilot plants, in process related aspects such as reduction of energy consumption, Minimum Quantity Lubricant or no-coolant machining, vibration analysis, external field assistance to reduce the energy needed for the process.

The pilot takes into consideration aircraft components; specifically the belly fairing of A380, a primary structural element supporting the exterior and aerodynamic panels and requiring a very strict tolerance. This component consists of different T-shape profiles with curvature, made of titanium or aluminum alloy depending on the exposure to corrosion. The machining of this highly precise and value-added part is very exigent and shall be improved mainly regarding its eco-efficiency aspects. This aerospace pilot plant is integrating the technological developments carried out at different production level: process, control and plant planning.

The concept of EMC2-Factory at process level is demonstrated by the effectiveness in aspects such as fluid or coolant reduction, increase of cutting tool life and energy consumption reduction. A factory design approach, integrating environmentally friendly process technologies with novel control systems through multi-objective simulation and optimization, to maximise production systems efficiency reducing resources consumption, is used in the pilot demonstration activities. For that, the aerospace pilot plant is integrating advanced energy measuring and monitoring sensors, as well as intelligent process strategies for resource and energy reduction.



Significant results

The table below includes the Identification of the result, a brief definition of the implementation, the achieved result and the TRL (Technology Readiness Levels).

Identification of the result	Description	Achieved result	TRL
Control strategies	1) Auto-switch-off of the machine after the machining program finished 2) Auto-stand-by mode of the machine after a programed waiting time 3) New hydraulic system design and control 4) Chip removal system	1), 2) Almost negligible savings due to Stand-by (2.2%) and Auto-stop (0%) algorithms are reported. This result comes from the extreme high load rate of the machine (0.3% time of non-use per year) that makes that these algorithms would almost never works in this machine. 3) High savings due to new algorithms for control the hydraulic system are reported: 19% of OMEC. 4) High energy savings are reported due to new chip removal system: 6.1% of OMEC	**TRL 6**

Identification of the result	Description	Achieved result	TRL
Analysis of energy consumption (mean values) - Assessment tool	Microsoft-Excel based tool, "Assessment Tool", was developed for the evaluation of the energy efficiency of the main components of a machine tool and for the calculation of the profitability of changing these components for more efficient ones	Is useful for the evaluation of the profitability of changing some machine components and, for the comparison of different machines by the acquisition of a new one	**TRL 3-4**
New MQL Ti Machining Technology	Analysis of the MQL performance compared with the traditional coolant for lubrication of Ti machining	Less hazard refrigeration and environmentally friendly solution. With a **carbon footprint reduction 37% and a 20% reduction of energetic power consumption**	**TRL 7**
Feasibility of FSW as Assembly Technology	Friction Stir Welding (FSW) is a promising alternative, preliminary FSW trials have been launched in order to measure power consumption, processing times and associated wastes and perform a trade-off study of both technologies; riveting and FSW	More automated and sustainable solutions. With a **carbon footprint reduction 51% and a 33% reduction of energetic power consumption**	**TRL 4**

Identification of the result	Description	Achieved result	TRL
Analysis of energy consumption per part (CAD calculation)	Development of a software based solution which can evaluate the energy consumption / energy efficiency of production machines by the use of a simulation approach	With the simulated energy demand, as base line scenario several "virtual" optimizations measures can be adopted (**electric energy demand** of the machine centre could be "virtually" **lowered by 43%** compared to the standard process and machine configuration)	**TRL 3**
Strategy for environmental assessment and optimization of aeronautic manufacturing plants	Monitor key performance indicators in relation to energy and resource use, at the machining facility	Serve as a source for obtaining **efficiency indicators** for the production of the different aluminum pieces	**TRL 4**

WP8 - Automotive industry pilot

This work package focused mainly on integrating and applying solutions (concepts, methods and technologies) developed in previous WPs in the automotive sector. WP8 consisted in four tasks going from preliminary concept of the pilots (task 8.1), to design and development (task 8.2), then to implementation of EMC2F solutions and in conclusion with testing and evaluation off the pilots (task 8.4).

In the first period (M15-M18) the partners focused on the identification of the pilots and the analysis of the solutions developed in the project in terms mainly of two different criteria: feasibility and potential eco-sustainability impacts on the automotive sectors.

In the second period (M19-M36), the activity started with the conclusion of the concept phase by identifying the final industrial plants of Bielsko Biała, Iveco Turin, Melfi and Pomigliano. For those plants, the WP8 activity planned to develop in details the best solutions for the two automotive sectors, where COMAU is supplier: car body and powertrain components manufacturing.

The demonstration activities, both in car body welding and powertrain demos, have shown, through the combination of monitoring, simulation technologies and solution engineering, the correct path to deploy an eco-sustainable management of the factories as iterative process.

Body welding automotive manufacturing demos have been focused on a typical assembly and welding line of car body. Both overall global strategies, and detailed subsystems topics have been deeply analysed from the energy sustainability point of view.

Powertrain automotive manufacturing demos focus on typical machining lines for cylinder heads and cylinder blocks engines. The main results have been obtained in the areas of systems retrofitting (brownfield), and analysis and simulation for new production lines (greenfield).

The sub-projects identified as the most relevant for WP8 activity are the following (B=Body Welding; P=Powertrain):

- SP8.3.1B, Joining energy process optimization;

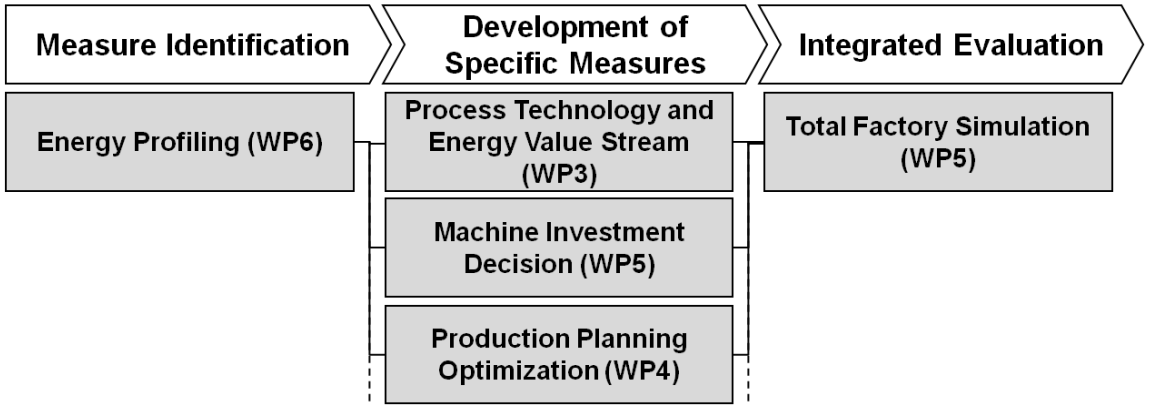
- SP8.3.2B, Welding line lightening;
- SP8.4.1B, Fluidics circuits optimization;
- SP8.4.2B, Integrated drives;
- SP8.5.1B, Dynamic energy simulation of welding lines;
- SP8.5.2B, Life Cycle Evaluation;
- SP8.6.1B, Data collection and monitoring;
- SP8.3.1P, Machine Structural Lightening;
- SP8.4.1P, Energy Machine Modelling and Control;
- SP8.5.1P, Decision Making Tool;
- SP8.6.1P, Green Retooling;
- SP8.6.2P, Data collection and monitoring.

Significant results

- Definition of the automotive body welding pilot environment
- Definition of the automotive powertrain machining pilot environment
- Pilot specification including technology testing vs. eco-performance assurance

WP9 - Rail industry pilot

The main aim of WP9 was to demonstrate the applicability of results from EMC2-Project within the Rail industry pilot. Five measures have been identified for the Rail Industry Pilot. The overall storyline of the activities is shown in the figure below.



An overall storyline of the activities defined in WP9

The factory for the pilot case is a Siemens Train Factory located in Vienna. First analyses have been driven by Siemens AG with contribution of all partners involved in the WP9. These analyses brought to the identification of the specific focus of the pilot on a building in which main processes are conducted (machining and welding). This building was chosen because it was representative of common processes for train manufacturing, because of the complexity of the material and production flow and because it had already been improved from energy perspective (building improvements) – hence more than state-of-the-art solutions had to be investigated. TUB IFW together Siemens AG applied the approach developed within WP6, made several energy measurement campaigns to identify hot-spots and driver in the selected case, and carried out an extended energy value stream of the production processes that take place within the selected building. Several measures have been investigated and some of them have then developed and implemented. In particular FESTO and TUB IWF contributed to development and implementation of the smart pneumatic monitoring system and

energy management system. The other measures have been mainly driven and implemented by Siemens AG. Siemens (Austria) being the responsible for the selected factory provided all the factory-specific information about processes/building/machines and provided continuous feedbacks about the implementation of the research results.

Significant results

- Development and implementation of Energy Management System in the selected building
- Development and implementation of planning tool that consider also energy to support daily planning decision-making
- Development and test of smart pneumatic monitoring and control at selected workplaces within the pilot building
- Comparison of current welding technology (GMAW) with alternative (FSW and laser technologies) from energetic viewpoint
- Test of additional components and control policies to reduce energy consumption on welding and machining processes
- Apart from the results, general insights such as the relevance of transparency, the importance of a comprehensive approach (production + TBS + building) and the difficulty of justifying measures from financial perspective have been confirmed also within the WP9 activities
- All results have been described in detailed in the Deliverable 9.1 "EMC²-Factory pilot demonstrators for the Rail industry"

WP10 - Exploitation, Dissemination, and Innovation Transfer

The main objective of this work package is to assure that the outcome of the project will flow into cross-sectorial European industrial companies as well as the academy through appropriate communication, and exploitation activities. Hence, the WP was structured under the following tasks:

- Task 10.1 "*Business strategies for exploitation*" has carried on the planning and coordination of the whole consortium activities for successful delivery of the project solutions to final users. The task has provided a detailed plan of use of the project exploitable results by each partner (individual exploitation plans) as reported in project Plan of Use and Dissemination of Foreground (PUDF) document, delivered in a first version (M21) and a final version (M36), as seen from different points of view, such as technology providers, universities and end-users. Furthermore, the task has provided in the PUDF the collective strategy of the project results utilization together with a detailed risk analysis and action prioritization of the key exploitable results. Finally, the task has provided integration of planning and control of the whole delivery cycle of the project solutions, which include activities of the tasks T10.2 "Dissemination" and T10.3 "Community building and innovation transfer ".
- Task 10.2 "*Dissemination*" has provided the definition and control of Strategic Dissemination Plan, including the development of project dissemination KPIs and their continuous monitoring. The task has provided design, development and update of all the project Public Relations materials, such as project website, project flyers and posters, presentation formats, and, finally, has delivered a 50 pages full color printed and electronic format brochure. The project brochure has been built with the active collaboration of FESTO and all the consortium partners that have provided nice and interesting brief descriptions of all the project exploitable results in the application pilots. The project profile and exploitable results in the brochure have been made available on the web on the EFFRA innovation portal (www.effra.eu) as well. The task activities have included a measurable plan of participation to high impact events such as international level scientific conferences (APMS2013/14, GCSM 2014, etc.) and industrial workshops for both and LEs and SMEs, such as Lamiera (Italy), Industrial Technologies (Denmark, 2012), Industrial

Technologies (Athens 2014). Task 10.2 ha guaranteed a significant exposure to both industrial and academic communities by establishing new links (and strengthening the already existing) with well-recognized international and national associations, such as EFFRA, CIRP, IMS. The task has planned and performed publications and special sessions in high ranked international conferences and journals. In particular a consortium partners task force has organized and contributed with papers to the Special Sessions in conferences IECON 2013 (Austria) and APMS 2014 (France). The academic partners have updated their university courses and, by their "learning factories" laboratories, have provided to managers, academics, students and general public effective hands on experiences of the solutions developed in the project and of their benefits.

- Task 10.3 "*Community building and innovation transfer*" has guaranteed the industrial spread of the research developed in the consortium, in close connection with European research associations and Science and Technology Parks, by involving the companies potentially interested in the project in seminars and workshops focused on industrial impact. The actual experiences and success stories of the project have been directly presented to the audience by the industrial partners involved in the pilot applications: the seminars, designed in order to allow effective delivery to both LEs and SMEs, have been completed by strategic Q&A sessions. For instance, in this context, workshops, seminars and strategic and visionary discussions have taken place in Kilometro Rosso S&T Park (Italy), MUSP (Italy) and in important industrial fairs, such as EMO Hannover (Germany) and BIEHM Bilbao (Spain). Furthermore, seminars and publications tailored to non-scientific public and magazines (e.g Sistemi & Impresa magazine in Italy) have been delivered.

Significant results

- The overall work-package strategy and plans have been developed and shared with the consortium partners establishing a common vision.
- A common branding image has been devised, by means of project logo and coordinated graphic design, and enacted accordingly in the project website, presentation, flyer, posters.
- Project exploitation / dissemination on community building activities have been strategically planned, performed and monitored, together with the design and continuous update of dissemination material and website.
- Four scientific publications and eight industrial targeted events (including worldwide- level workshops such as APMS 2012 and Industrial Technologies 2012) have been delivered (data updated 23/4/2013).
- Several wide audience events such as Siemens and POLIMI workshops in Industrial Technologies 2012 (Aarhus) and the upcoming workshop in EMO 2013 (Hannover) are included in project community building/dissemination activities, together with CECIMO communication activities.

Potential impact and main dissemination & exploitation activities

The following information can be found also under the PUDF document ("Plan for Use and Dissemination of Foreground") submitted by the consortium. The exploitable results (ERs) achieved by the EMC2-Factory project are reported in the following table. As can be seen, the number is high (34). Nevertheless, following an Exploitation Seminar (ESIC) delivered by the EC services to the consortium, it was decided to concentrate the analysis of potential impact and market share, on a lower number (13) of ERs (see Chapter 4.2, part B2 in this document).

#	Exploitable result	Description	Added value/benefits
1	Guidelines for the use and implementation of ECO friendly solutions	The book of guidelines will be the basis for company training and source for consulting and implementation activities. Further R&D activities in the company will be based on the knowledge accumulated in the project.	Improved knowledge and methodologies for ECO Factory.
2	Holistic perspective of eco-factories	The holistic perspective is a novel approach that supports manufacturers in assessing the factory performance from the production, economic and environmental viewpoints in an integrated and systemic approach. The holistic perspective supports design and operations at the levels of the factory and for various decision makers (industrial engineers, production managers, etc.) including all physical systems (production systems, TBS, workforce, building shells, etc.) together with the related business policies and control rules.	To strengthen POLIMI presence as participant in the various boards of international organization and to improve student education level
3	Standards for design of green production line configuration	Introduce common approaches for designing green production line configuration within Siemens	- Increase green awareness among production line developers within Siemens - Ensure use of proper methods and tools to design green lines
4	Improvement of WCM strategies to be implemented in European FIAT plants	Implementation of energy control and saving strategies to FIAT plants	Improved energy efficiency of plant
5	Expanding consultancy capabilities for advising green production line solutions	Introduce common approaches to advise eco-investments according to environmental and financial needs of end users	To strengthen energy efficiency proposals for new/existing plants
6	Standards for green factory planning	Introduce common approaches for planning green factories within Siemens	- Increase green awareness among factory planners within Siemens - Ensure use of proper methods and tools to plan green factories
7	Methods and tools for green factories	Method and tools to be used within internal consulting offer for planning and operating green factories, improving energy efficiency of manufacturing process	- Internal business through green factory planning and operation consulting - Integration of green aspects into daily in-house consulting activities
8	VDI Standard for resource efficient factory planning	Standard process for planning resource efficient factories	- Use of standardized method for planning green factories - Green awareness and common understanding
9	LCA configurator for factories	method and tool to be used for retrofitting and operating green factories, within internal consulting offer or on site with training offer	- Increase green awareness in factory planning and operation within Siemens - Ensure comparability and benchmark capability for continuous improvement and strategic decision
10	Tool for production planning support	The tool for production planning developed in WP4 will be tested in different areas of Vienna and (possibly) in other factory to increase the implementation	- Support production planning - critical activity of several Siemens factories

#	Exploitable result	Description	Added value/benefits
11	Energy evaluator for machine tools	How to approximate the energy demand of machine tools by simulation	Determine the energy demand of machine tools without local measurements
12	Rapid Simulation Tool	Quick and intuitional evaluation of production lines regarding production performance as well as resource consumption.	- Improved control strategies regarding resource consumption as well as production performance, - hands on evaluation results without much time for preparation.
13	Life Cycle Evaluation Tool	Evaluation of environmental and financial impacts of factory systems over the entire life cycle.	- Transparence about TCO and CO_2eq. of the factory system, - Easy comparison of alternative strategic factory settings.
14	Dynamic Energy Value Stream Analysis	Real-time assessment of the energetic intensity of single processes and products in existing process chains.	Quick benchmarking of energetic relevance and impacts of organizational and technical changes in process chains
15	Smart Distribution Network	Monitoring units in distribution networks recognize demand and non-demand (e.g. leakages) and ventilates/shuts-off branches of the supply net to reduce energy losses without compromising operator comfort	reduced leakages, new control algorithms based on smart flow analysis
16	3D indoor monitoring climate tool	Thermal emissions represent the greatest energy inefficiencies in machine operation. At the same time, much energy is consumed by HVAC systems for heating and cooling to improve conditions for machines and operators. The heat emission analyzer allows detailed monitoring of heat emissions for improved HVAC control as well as the possibility to extract temperature models of machines that can be used for factory floor plan optimizations.	- Improved HVAC control - Floor plan optimization - Anomaly detection
17	Expanding consultancy capabilities for advising most energy efficient technologies in welding and joining	Advisory to apply the most suitable welding technologies in manufacturing processes. Suitability defined in function of energy consumption and achievement of designed mechanical properties	- Cascading benefits to hundreds of industrial members; high impact in manufacturing efficiency and environmentally friendly operations.
18	SAW sensors for dynamic monitoring of machines / tools	With the increase of machine processing speeds, with the introduction of new materials for the manufacturing of micromachined parts, a highly dynamic monitoring of the machine (at the tool level) is now becoming mandatory. Classical methods for direct measurements require intrusion in the process; indirect methods are often complex to use in such environments. Therefore, the use of wireless and passive SAW sensors (miniature strain gages installed directly on the tool) opens new possibilities offering clear benefits to the machine owners (see next column).	* respect of machine tolerance levels (increase life time of the machine) * insurance on the quality of manufactured parts (increase yield of the process) * reduction of machine downtimes (and reduction of maintenance time) And as a consequence, a very important reduction of energy consumption.
19	Energy efficient machine Control strategies	Algorithms to reduce machine consumption based in PLC programming	to reduce machine consumption as sell´s argument
20	New MQL Ti machining Technology	Validation of MQL strategies for Ti milling	to strength sell´s arguments of milling machines

#	Exploitable result	Description	Added value/benefits
21	Sensing and monitoring strategy for energy transparent factories	Method to systematically increase energy flow transparency in support of metering and monitoring hardware as well as virtual metering points.	Achieving the highest possible degree of energy transparency with the lowest feasible effort in terms of human and hardware resources. Energy transparency directly benefits the efficient operation and planning of factory systems integrating production machines, technical building services and industrial infrastructure.
22	Guidelines for Actuation Technologies	Beside other sources, the guideline will be a base for training courses and consulting activities. The knowledge is also base for further developments in the research department of Festo	-improved knowledge about pneumatic applications
23	Assessment tool for actuation technologies	Basic research on contents for software modules was prepared in this sub project. The results will be included to a tool frame at Festo	-methodologies for efficient design of applications
24	Advanced Control for Drives	Results from the demonstration of advanced controls for drives will be further shifted to the development of new actuation technology	-reduction of air consumption during operation of pneumatic cylinders
25	Validation of pneumatic Module for advanced monitoring and control	The tests which ran in EMC²-Factory and the demonstration activities gave input for validating products in prototype state. The results will be used for optimization of this product	-advanced monitoring and control options for machines
26	ECO-Plant strategies with Model Predictive Control techniques	Constraints both on the control actions and on the process variables require the adoption of hybrid control systems. The control system has to properly manage the shout-down of the operating machines on the base of a plant energy efficiency evaluation; The nonlinearities of the controlled plant must be driven; Different and distributed energy sources must be taken into account as possible energy supply system scenario. Model Predictive Control technique is able to manage control problems characterized by constraints both on the control actions and on the process variables by optimizing a performance formula.	Make available to the industry advanced control methods to be used as standardized techniques for factory optimized energy management and, in general, for manufacturing plant control applications (e.g. flexible transport lines management)
27	Decision Making Tool	Quick evaluation of energy consumption of production machines (Excel Tool)	During procurement: Quick evaluation of different production machines in terms of energy consumption
28	Measurement and Monitoring device. Multi-channel, multi sensor data logging device for machines and energy consuming equipment	Multi-channel measurement of analogue energy flow sensors (compressed air, steam, heat, electricity) with logging capacity for all channels into local usb drives or network databases. Standardized interfaces for available industrial sensors.	Synchronous logging of multi sensors for energy flow and power measurement in industrial machine tools, production equipment and technical building services

#	Exploitable result	Description	Added value/benefits
29	A procedure to build a state-model of machine tools for energy saving purposes	A methodology for building energy state-based models of complex machine tools using the automata formalism was developed. Instead of analyzing the whole machine, that may be complex, the procedure allows to analyze each functional module independently and with minor efforts. Moreover, the logic of the machine is modeled separately and the final model of the controlled machine represents only the feasible states of the machine according with a selected control strategy. The machine can be decomposed at several detail levels, indeed each functional module can be decomposed in components, functionally dependent each other. In order to give some examples of applicability, the achieved model can be used to select energy efficient functional modules or to evaluate impacts of different design alternatives at machine level. Furthermore, the model can be used to simulate the energy consumption during the production of a specific new product, or to evaluate energy efficiency improvements achieved through control strategies or other energy efficiency measures, within a certain production environment.	selection of energy efficient machine component
30	software for hybrid simulation of machine tools for energy consumption evaluation	The aim of this activity was to develop a software based solution which can evaluate the energy consumption/ energy efficiency of production machines by the use of a simulation approach. Basically, the most relevant functional modules for the energy consumption of a machine tool are modeled within Matlab/Simulink/SimScape. Foundation of the component models are mathematical equations describing the components physics. Then for controlling the functional module simulation models a control framework is needed which acts equivalent to the machine logic control of the mapped machine tool. The developed control framework is implemented within Matlab/StateFlow. It reads the information provided by the NC-Code interpreter and returns control commands to each functional module model. As a result, the model represents a hybrid simulation: Stateflow is used to specify the discrete controller where Simulink specifies the continuous dynamics of the functional modules. As a result the entire simulation model delivers the power / energy consumption of each simulated functional module as well as for the entire machine tool.	Currently, there is no software solution available on the market which allows the energetic evaluation of new machinery and retrofitting measurements of existing machines
31	Machine control policies for energy saving	Indeed, machine functional modules keep consuming energy during not productive states (i.e. when the machine is not being involved in part processing), because they must be available when the production has to be resumed. Energy efficiency can be increased by keeping the machine in low energy states when production is not requested. Specifically, several control policies have been investigated for switching the machine off when production is not critical, and on when the part flow has to be resumed. The policy parameter that minimizes the machine energy request is provided analytically or numerically.	This activity aims to increase the machine energy efficiency when production is not requested.

#	Exploitable result	Description	Added value/benefits
32	Energy simulator of machine tools	The ENEMAC simulator is a demo SW tool that allows the estimation of the energy consumption of a machine tool during the execution of specific part program of milling operations. The simulator consists of four modules. The NC emulation module (1) analyses an ISO part program and computes instantaneous reference position and speed of each axis along a generic tool path. Given tools, parts, and machine data, a Computational Solid Geometry engine (2) provides tool-workpiece engagement and material removal rate information over time. A cutting model (3), specifically conceived for energetic analysis, calculates average torques and forces taking into account cutting parameters, workpiece material and tool geometry. The energy evaluator (4) uses information extracted from the other modules (i.e. axis position, speed and acceleration; cutting forces and torque) and performs the energetic simulation of the whole machine, including the peripherals.	• Simulation and evaluation of a milling work cycle on a specific part program • Evaluation of different strategies of milling process • Energy estimation breakdown at the level of machine component / subsystem and individuation of the possible machine “weak points”
33	Green Control Processor	Methodology for energy efficiency monitoring and energy consumption anomalies detection. Green control processor reuses of existing control infrastructure in order to create on-line machine energy consumption profile by tracking information about energy consumption and its distribution between production phases and end-point devices. It detects over consumption of energy and generate energy efficiency alerts	Low cost solution for energy efficiency support.
34	Energy and resource flow assessment tool	Eco factory assessment at various level of the factory (machine to process chain to plant) and in different lifecycle phases (design to operations to re-design) is to be performed with multidimensional evaluation criteria. The tool provides a synthetic guide for the assessment process providing a quick and summarized set of indicators of productivity and efficiency that enables assessment under a formal view of the Eco factory (ref. Emc2-Factory deliverable D2.2) integrated under economic viewpoint	Enables evaluation (comparison of alternatives, benchmarking, management during operations) in a thorough and synthetic way of resource usage and manufacturing performance, fit for managers' needs and for experts as well

Moreover, chapter 4.2 ("Use and dissemination of foreground") is reporting the main dissemination activities that were performed, as summarized in 2 separate tables:

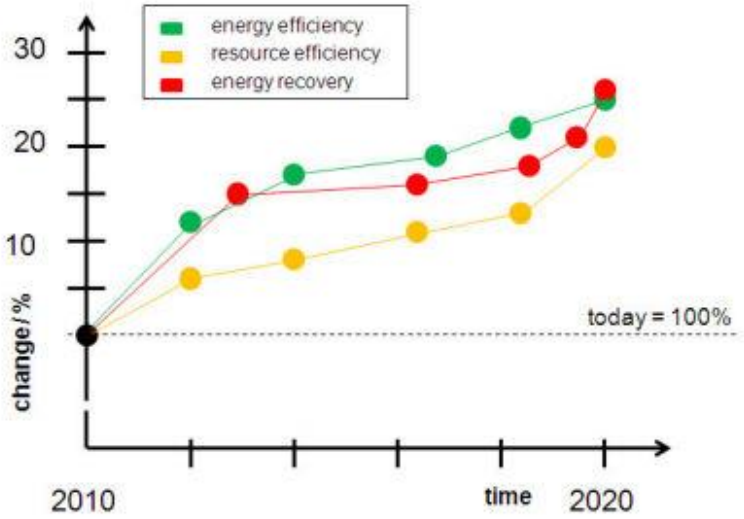
- Table 1 (Template A1): List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Table 2 (Template A2): List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

The project is dedicated to an overall approach. **The impact** expected from it is linked to partners' internal strategies for implementing new methods in the coming years, as it is very obvious that regulation on the one hand, economic advantages and also shortage of certain materials on the other, will force industry to go into this direction. The following figure indicates that the development of a holistic description of a green factory goes well beyond single domains of technology. It is based on a company internal strategic planning and shows that there are some important levers that are basically "non-technology" if one is used to refer for instance to reducing CO_2 emission to specific filter technologies or special combustion processes.
This way, the main areas are addressed that one has to observe and implement, when the goal is to reach significant improvements for energy efficiency, energy recovery or resource efficiency, as proposed by EU 2020 strategy. The work on these 5 areas is reflected in the project as following:

Potential for Improvement until 2020

Organization: refers to new ways of workflow and of including processes and line simulations at higher level of management decisions.
Logistics: On the one hand this is linked to "organization", on the other has to be discussed in terms on energy footprint.
Control: Control issues start at control implemented in machinery, but also for aligning cells and lines. At the same time control refers to higher level software which links shop floor events and decisions directly to management procedures and planning.
Shop floor operations: questions concerning energy and resource efficiency as well as energy recovery on "normal" shop floor operations.
High energy operations: reach a high standard of material substitution or minimizing energy use for certain processes.

The discussion of these levers leads to the following picture of estimated impact (change compared to today's level in %) versus time, the final goal for 2020 being defined by the EU 2020 Strategy.



Estimated impact of results versus time

Impact in more detail – can be seen under four areas of focus:

- **Impact 1:** Increase in competitiveness and sustainability of manufacturing processes, by advanced design options and guidelines for the manufacturing of new greener products with tailored properties, e.g. using additive manufacturing to decrease waste.
- **Impact 2:** Strengthening the environmental performance of the eco-factories by reducing resource consumption, energy and waste by at least 20%.
- **Impact 3:** Improving the development and access to markets of innovative environmental technologies, helping SMEs adapt to emerging market needs and protecting and creating new job opportunities.
- **Impact 4:** Knowledge of new scientific, technical, economic and social factors to support European policy development and the standardisation and definition of eco-labelled processes and products.

"Secondary impact" can be observed as a consequence of the work of academia and research: the project interlinks important research organizations and universities as well as an important association. All of them will have significant share in multiplying the impact of this project. The goal is the fulfilment of the Europe 2020 strategy of the European Commission, a strategy that is covering a ten year time span. This means that the results of today's industrial projects from our partners of the research institutions will have reached the implementation stage. Therefore the thinking and work of the EMC2-Factory project will be multiplied, with universities consider that the young researcher now to be working on the project will have several years of working experience in 2020 in companies that have no other choice but to move towards the green factory which also means the results we produce are multiplied in their impact. The academic partners have an impressive list of projects, lectures and publications that are relevant for the Call's topic and are / will be taught to their students.

Project public websites

Project logo(s) and diagrams can be found on the project website: http://www.emc2-factory.eu/ . Photographs illustrating and promoting the work of the project, as well as the list of all beneficiaries with the corresponding contact names can be found both on the project website and the EFFRA Innovation Portal: http://www.effra.eu/ .