PROJECT FINAL REPORT

DAPhNE

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Project acronym: DAPhNE

Project title:
"Adaptive production systems and measurement and control equipment for optimal energy consumption and near-to-zero emissions in manufacturing processes"

Funding Scheme: Collaborative Project

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EXECUTIVE SUMMARY

The acronym DAPhNE stands for “Development of Adaptive ProductioN systems for Eco-efficient processes”, and is identifying a FP7-project co-funded by the EU, which aims at developing new processing solutions for achieving Eco-efficiency in three important European manufacturing sectors: Ceramics, Cement and Glass. The overall scope of DAPhNE project is to develop and demonstrate a package of integrated solutions for energy intensive processes, based on substituting high temperature heating with micro-wave technology (not yet implemented as a full-scale industrial process) and developing a set of smart monitoring and control solutions for providing real-time information about the energy consumption and product quality on the basis of KPI.

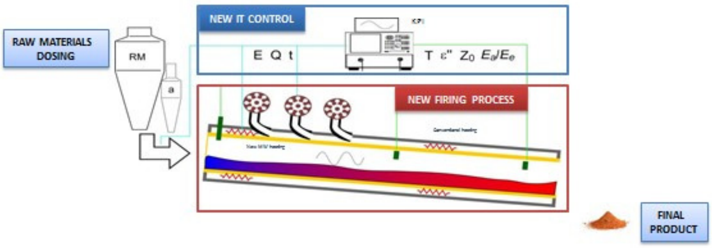

Figure 1. Project scope

Global energy demand has grown widely during the last decade. Now, it is no longer a surprise that the largest slice of the “primary energy cake” is used for heating. Heat and electricity dominate the total end use and represent approximate 55% of the total energy use (57.3 EJ). Even though the use of natural gas and electricity for heating (accounting for 66%) is common to several sectors (e.g. residential, service, etc.), the industrial sector still represents the most-energy demanding.

These 3 sectors (ceramics, cement and glass) have already implemented technologies, control systems and measures to reduce primary energy consumption and plant emissions. However, several improvements could still be done in order to achieve eco-efficiency, especially for what concerns the most energy intensive parts of the production chain: the firing processes. The Scientific and Technological (S&T) approach of the DAPhNE project addresses research and development (R&D) actions at both local level (MW heating) and global level (innovative monitoring and control systems for assessing energy consumption).

The partnership consists of materials manufacturers as end users (KERABEN, ASCEM, CEMEX Central, SANTOS BAROSA), Universities/Research Institutions with strong expertise in the different aspects of the project (AIDICO, NTUA, CSIC-ICV, UPVLC, CEMEX Research, STRESS, UNIVPM, TUBAF, IST, FRAUNHOFER), large engineering companies like TECNICAS REUNIDAS (as an expert in high temperature continuous processes, industrial furnaces and auxiliary equipment), SMEs like CEINNMAT (an engineering company deeply involved in material processing), MUEGGE (a worldwide well-known MW components & equipment supplier) and FLO-IR (a specialist in thermal analysis).

First a lab-scale prototype, and later a semi-industrial prototype with two different modules for processing 5 target materials (ceramic frits, clinker, slag cement, metakaolin, and glass) were developed, and resulting products were positively confirmed for the 5 target materials. The goal for clinker raw meal was the calcining at the beginning but finally the complete processing of clinker was possible in the semi-industrial prototype. In this sense, the project challenge was obtaining a reduction around 40% in the consumption of energy resources, achieving high productivity rates and with less environmental impacts by a reduction in the process emissions far below the prescriptive limits and standards.

SUMMARY OF THE PROJECT CONTEXT AND OBJECTIVES

It has been observed that in Europe, according to actual situation, there are important needs to develop new firing processes.

More than 10 EJ are demanded by the industry, which is the **25%** of the total **energy** used in Europe.

The manufacturing sector represents the **26.8%** of **employment** in Europe and the **22%** of **CO_2** emissions (greenhouse gases). The **50%** of that energy is demanded by Chemicals + Petrochemicals + Iron - Steel of the total industry and the other 50% of the energy by light industry.

A demand of 172 EJ is expected in 2030 if no measures are taken.

High Temperature Microwave heating has not been implemented at full-scale in industrial-processing. The overall scope of the DAPhNE project was to develop and demonstrate this technology in the high intensity demanding process.

The general objectives of **DAPhNE** project were to develop and demonstrate:

- **Operational control and monitoring methodologies** for the automatic control of the alternative firing technologies during the process.
- **Smart energy control and monitoring solutions**

  Development of electrical and thermal energy control and real time monitoring solutions for plugging-in the alternative firing systems to the existing processes, to ensure minimization of energy consumption.
- **Coupling MW with materials**

  Adaptation and coupling of high temperature alternative firing systems, treatment systems, and new solutions to each intended product.
- **Development of process manufacturing modules**

  Development of adaptive, modular, process modules in manufacturing processes of mass commodity products.
- **KPI's**

  Definition of KPIs for each system, process and material based on monitoring data from demonstration, on the developed parameter database, as well as on extended LCA.
- **Business models**

  Development of techno-economic, market and business models ensuring economy-ecology and sustainability to accelerate the short term and wide spread implementation of the new MW tech.

And the expected impacts of the results:

- **Ultra fast processing** in processing of materials **based on MW** kiln application.
- Electrical efficiency and therefore **energy savings thanks to electronic controls** on MW systems.
- Possibility of **modular production facilities.**
- **Saving in the dust emission** during processes.
- Sustainability: **up to 85% decrease on CO_2 emissions.**
- **A flexible manufacturing system** to react automatically in case of changes, whether predicted or unpredicted.

- **Diversification of raw materials suppliers** since not so pure materials are expected to be needed.
- **Product diversification.**
- **Kilns can be stopped** i.e. during weekends, something which is unthinkable now.
- **Saving in transportation** of raw materials due to reduced batches.
- **Lower maintenance** cost of kiln per year.
- **Improving system robustness.**

The proposal addressed the manufacturing of 5 target materials: ceramic frit, glass, clinker, slag cement and metakaolin. The summary of basic specification of firing and compositional properties is in Figure 2 and Figure 3. A two modules demonstrator for processing five target materials was developed and resulting products were positively validated.

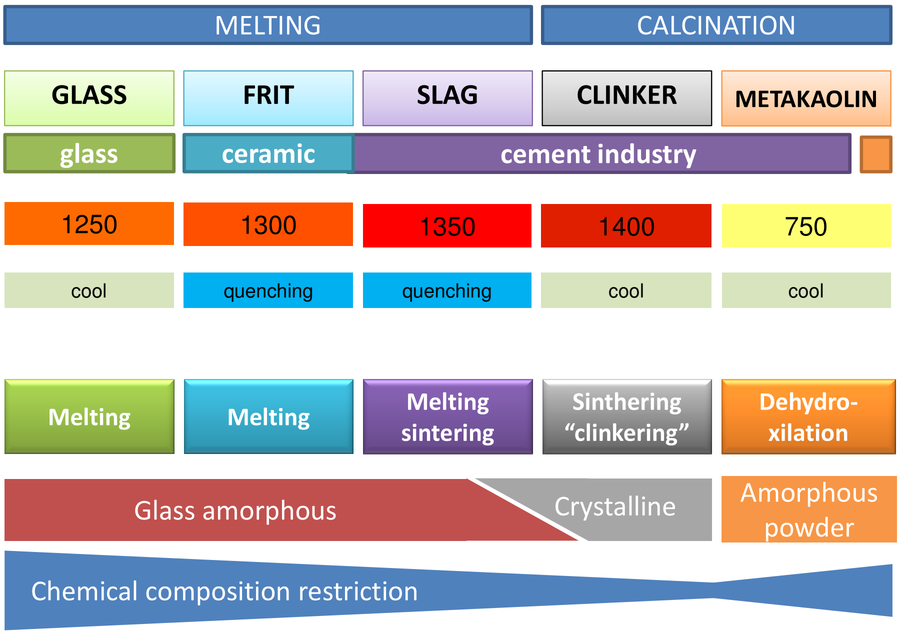

Figure 2. Microwave process stages.

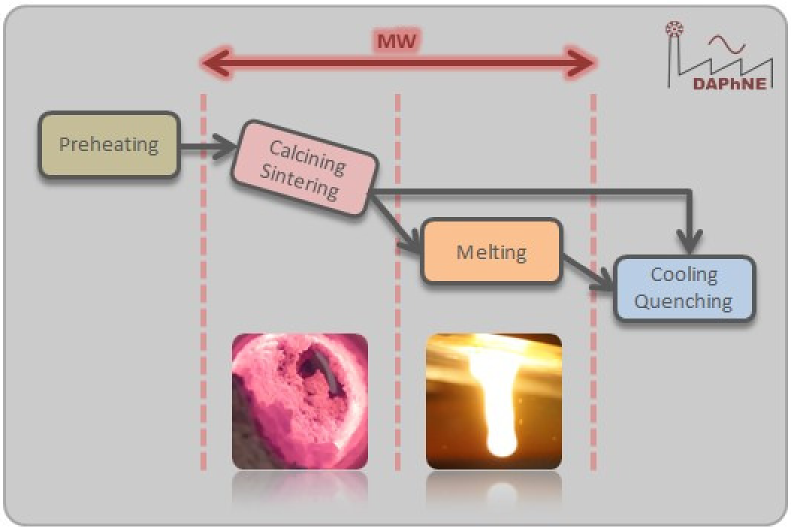

Figure 3. Microwave process stages.

The concept of the microwave kiln in DAPhNE taking into account the whole process is shown in Figure 4.

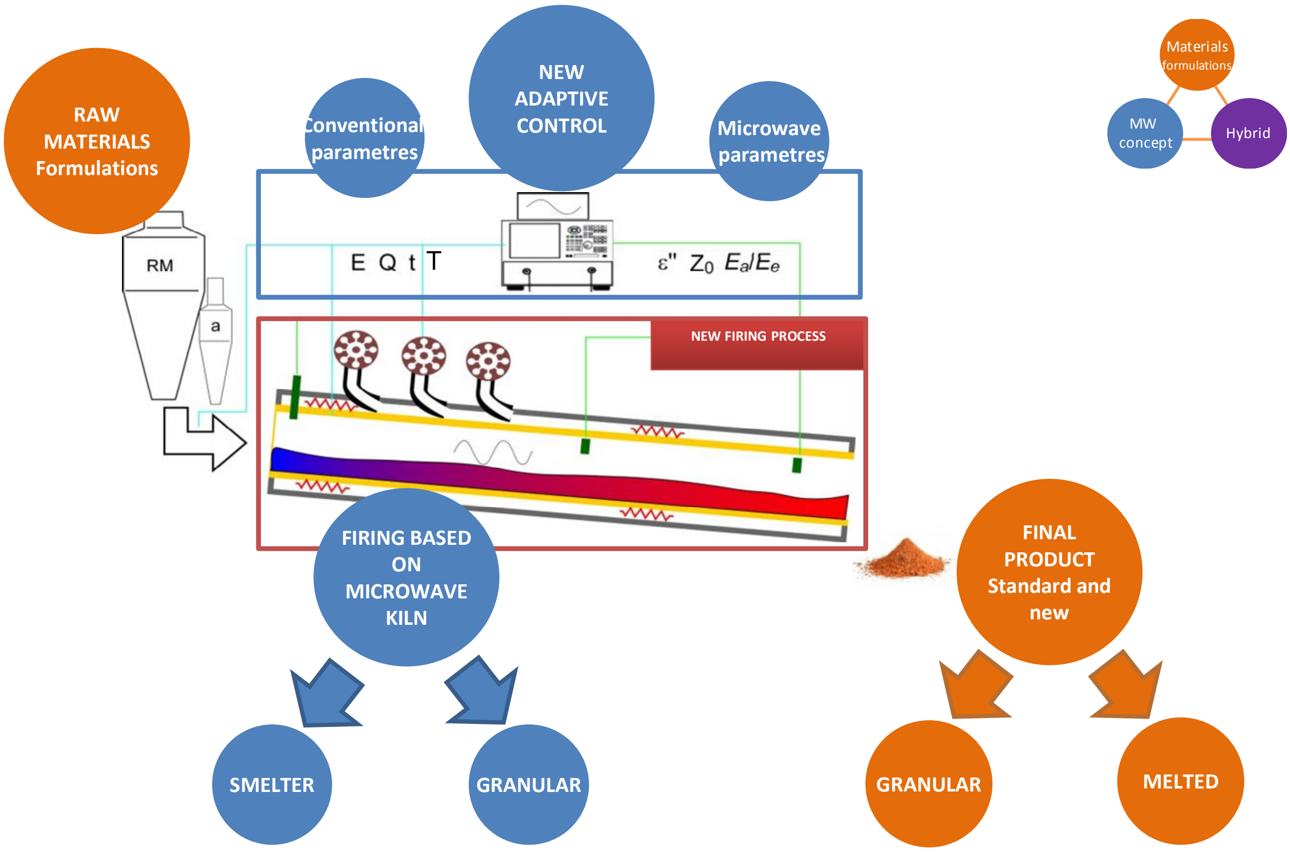

Figure 4. Microwave kiln concept.

The most important ADVANTAGES and LIMITATIONS are:

ADVANTAGES	LIMITATIONS
• Rapid heating to operating temperature • Minimal delay before ready to use • Total volume heating • Uniform heat distribution • Selective heating • High control and process speeds • Only product is heated, energy save • Compact units save space • Flexible modular design • Reliable with an intelligent service and maintenance concept • Environmentally friendly • Fully electrical	• Dependence on the materials properties • Run-away risk an • Tunning according with the material • Sensible to variation of the properties during heating • Limited size. Residence time conditioned by the dimensions

MAIN S&T RESULTS/FOREGROUND

The Scientific and Technological approach of the DAPhNE project addresses research and development (R&D) actions linking innovative energy production systems from the system level to the plant energy management via development of adaptive processes, active control and real time monitoring of systems and processes.

The vertical R&D and demonstration activities (5 Work Packages) are complemented by three horizontal work packages addressing the definition and evaluation of appropriate KPIs, integrated LCA, MCA and MOA to support decision making, EMS supporting actions as well as dissemination ad exploitation activities. Project management and coordination of the Project is performed under a separate WP (WP1).

The summary of more significant results obtained in each work package is below.

Technical actions.

- **WP2.** Developed at the beginning of the project to establish the boundaries of each manufacturing process.
- **WP3**. The main objectives of this WP are the characterization of the raw materials and final products and the functional design of microwave prototypes. So new raw materials compositions have being formulated to be processed by a new adaptive MW system especially designed and developed for them. The whole DAPhNE process was divided into three global stages: preheating, microwave heating (embracing the sintering and/or melting stages) and cooling. To cover the microwave stage different microwave structures were carefully designed, evaluated and tested at lab scale and by simulations. In this task special attention has been paid to the design of the necessary filters to avoid microwave leakage from the open applicators. The main result has been the construction of a laboratory scale prototype, which is fully operative for the 5 types of materials even though the prototype and its different modules for sintering and melting were improved and optimized as well as process operating conditions. Final products resulting from prototype were validated according to current industrial quality tests for each type of process.
- **WP4.** This work package deals with the evaluation of different instrumentation solutions for measuring and monitoring the DAPhNE process, the development and lab scale testing of the instrumentation systems for monitoring the critical variables of the new processes, the development-implementation-validation of an adaptive control system, the design of the data transmission system for providing communication services amongst all the nodes at single process level and for the later integration of the new process at factory level and the definition and development of the DAPhNE production process model which has been the basis of the DAPhNE Simulation Module within WP6.

  The creation of a 1-D model which can predict data from the validated prototype and 3-D simulations in COMSOL were performed. The final definition of the monitoring infrastructure layout for the demonstrator (UNVIPM) was subjected to changes in case the configuration of the DAPhNE processes was changed. Regarding control architecture, the Process Flow Diagram (PFD) was updated accordingly to new process lay-outs of the demonstrator. P&ID´s have been developed and updated showing the control loops established for the demonstrator.

  The instrumentation for direct monitoring of the different subsystems of the demonstrator has been installed completely. An intense work on indirect monitoring and measurement techniques has been also conducted during this second period and it has been successfully completed. From the side of the microwave components of the demonstrator, the 915 MHz microwave system was set-up and put into operation in KERABEN's facilities, also needing dedicated support to adapt the PLC of the control system to the microwave system.

An OPC communication protocol has been developed to manage the numerical model undertaking the calcining stage simulation. The GUI that shows the output on screen is part of the HMI. A format for saving data coming out from the model has been also defined

The final solution for the monitoring infrastructure consisted of five measuring levels: Level 1 for the total consumption of the system; Level 2 for the consumption of the preheating stage; Level 3 for the consumption of the power supply; Level 4 for the consumption of the chiller, and Level 5 for the consumption of the auxiliary loads which represent a total below 1 kW that are not broken down and monitored individually. The power analysers and accessories were purchased, integrated and are fully operative in the control cabinet. Simulations of DAPhNE production process model and the defined configuration sets have been carried out and the resulting values have been evaluated and documented.

- **WP5 and WP9**. During this period an important tool was developed within WP5 by combining the COMSOL numerical models with a MATLAB routine, this routine automatically changes the operations variables (Input Power) in order to respect certain constrains of the system as for example the maximum material temperature or the minimal reaction efficiency. This has been important to evaluate the performance of this type of microwave cavities and to make a comparison study of the performance results for the 2.45 GHz and 915 MHz cavities.

  Regarding demonstrator, it has to be highlighted that during this period, the integration of all the components, the development of the detailed engineering and the purchasing of all the components were performed. The Demo site was ready to start with the mounting stage according to the planning. In March 2015 people from TR were moved to the Demo site in order to start the installation of all the components and supplies according to the layout established in previous tasks. Moreover, the electric and control panels were installed as well as the electric and control wirings.

  A testing plan was agreed among partners. Mainly, the trials were split into 2, trials in the melting line (for frits, slag cement and glass) and trials in the calcining line (for clinker and metakaolin). Both, in the melting line and in the calcining line, good results were achieved and good product quality was obtained for all 5 materials involved.

- **WP6**. Different measurements for the KPI calculations for the lab-scale prototype processes as well as for the conventional lab scale processes have been performed and evaluated. Different improvements regarding the two prototype concepts have been incorporated resulting in better KPI values. It was shown that with the new microwave heating technology significant reductions in energy consumption can be achieved.

  In parallel, the search for conventional heating systems able to produce comparable lab scale data was continued in accordance with the technical coordinator and with the industrial partners. Additionally, measurements for comparable conventional heating have been performed and evaluated at TUBAF with batch furnaces whose results were discarded so an extensive collection of data from small scale to large scale furnaces was carried out to show the size dependency of manufacturing processes and allow for a correct categorization of the MW process.

FhG-IPA revised the latest prototype version of the EE & KPI MGT Simulation and Visualization Module to implement further functionalities concerning data handling and process model implementation and finalized it according to the defined requirements and system definition as well as implemented module functionalities with the focus on Energy Efficiency and KPI Management.

Support Actions.

- **WP7.** This work package includes LCA, techno-economic and market assessment, process validation against ISO50001. The market analysis has been carried out as well as an exploitation plan. The first steps for conducting the Life Cycle Analysis were done. The LCA allow to evaluate the relative environmental impact and to quantify the environmental footprint of conventional and advanced manufacturing process for the 5 different materials.
- **WP8.** Dissemination, training and exploitation road map. Project website (one of main dissemination tools), was launched by STRESS in month 3. The URL of the official project webpage is: http://www.daphne-project.eu/. Several public deliverables have been made available for download.

  During the last six months, UNIVPM conducted a survey among the Consortium in order to better picture the relevant stakeholders of the DAPhNE project.

  KERABEN, as T8.3 leader, has participated on several events as dissemination activities and keeps also periodic contacts with other projects like FACTORY ECOMATION. Besides, Keraben, together with UNIVPM, has already attended several meetings with the coordinators of FACTORY ECOMATION, FOUNDENERGY, EDEFU and REEMAIN projects, in order to perform clustering activities.

<u>Detailed results</u>

Prototype and materials

- Tests verified that the expected thermal processes occurred in the lab prototype for each material.
  - Frit production was optimized in melting prototype and the resulting product was positively validated. All the characterized parameters showed that the product is similar to the industrial one.
  - Glass production was optimized in melting prototype and the resulting product was positively validated taking into account that it's a resulting product from an intermediate step, since the stabilization phase is not included in the prototype and it's still needed for the achievement of the quality of final products.
  - Operating conditions in the prototype to achieve a decarbonation rate around 95% of clinker raw meal were optimized in calcining prototype. The mineralogical composition of the raw meal heated at 900-950ºC with microwave prototype is the same that the composition with conventional heating at the same temperature.
  - Taking a further step, lab scale prototype was used and clinker-like material was produced. The highest temperature measured was 1200ºC and produced

material was showing characteristics of the clinker produced in traditional way. It is suspected that locally the temperature is higher in the microwave kiln than measured using outside thermo-camera. Obtained samples of clinker are under investigation by the industrial partner.

  - Several batch mixes were tested to obtain slag cement product in melting prototype. Composition was changed in order to improve melting process. Chemical composition and vitreous phase were positively validated for different batch mixes.
  - Metakaolin production was optimized in calcining prototype and the final product has been positively validated, but it is necessary more amount of final product for a complete validation studying the pozzolanic reaction in cement mortars.

- The lab prototype was **integrated** with other systems (conventional heating, sensing, etc.) **in a complete laboratory prototype** for heating processes in continuous.

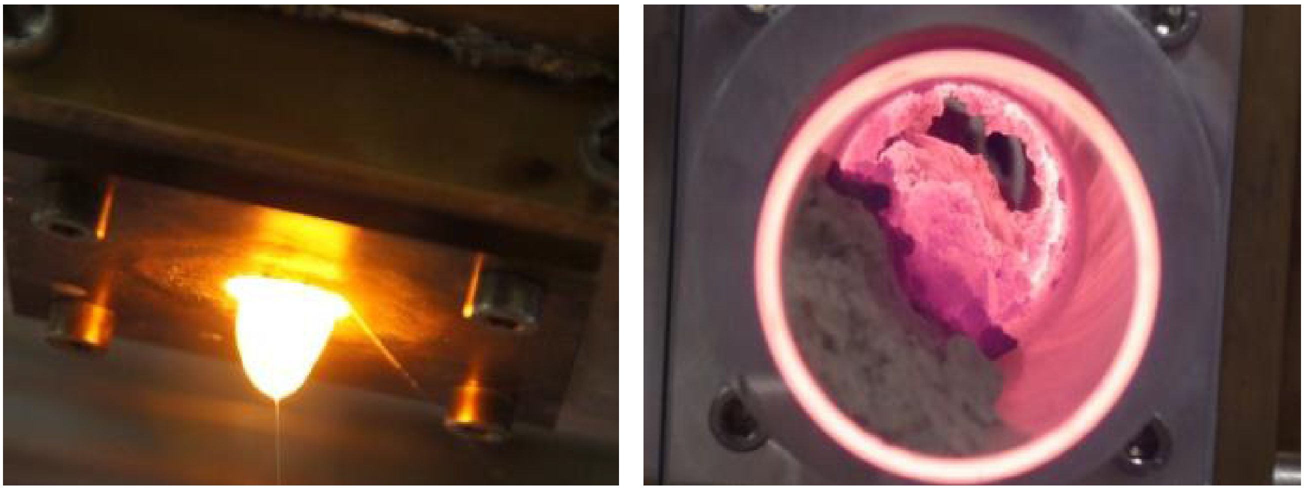

Figure 5. Material being processed in the two prototypes modules: melting (left) and sintering (right).

Adaptive control system and innovative monitoring solutions

The SCADA based control system has been implemented in demonstrator. Virtual sensors were integrated in the management of its DDBB to carry out real-time indirect measurements supported on numerical models to estimate temperatures inside the microwave kiln (
Figure 6).

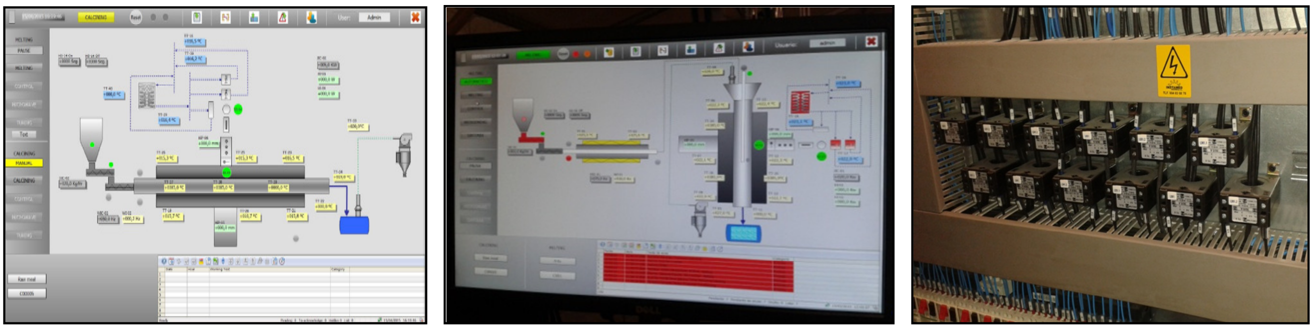

Figure 6. Control system and virtual sensors.

A multilevel energy measurement system to quantify the energy consumption in the demonstrator was implemented as well. The DAPhNE production process model was developed with all relevant objectives and parameters on the basis of the new heating processes concerning the real production chain of the DAPhNE demonstrator (Figure 7).

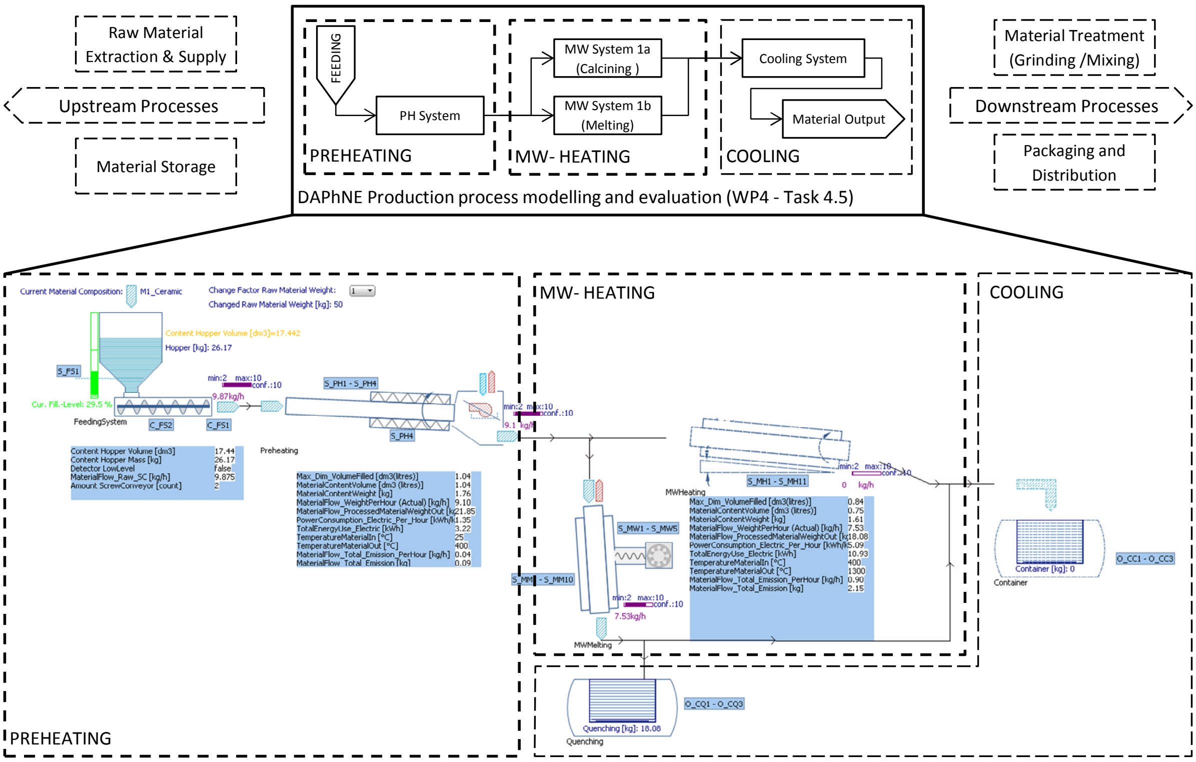

Figure 7. Production Process Model Overview and System Boundaries

Data exchange was implemented with the sensor and instrumentation devices of the DAPhNE demonstrator line. Validation and tests of DAPhNE production scenarios data analysis, user interface adaptions, visualization and reporting, process parameterization and other functionalities were performed by the partners

Demonstrator

A two modules demonstrator for 5 target materials was commissioned at Keraben facilities in order to carry out a testing plant with all the materials.

In the melting line, good results were achieved during this period and good product quality was obtained for the 3 materials involved. In the calcining line, trials in order to obtain calcined raw meal and metakaolin were performed. It has been proven that it is a feasible technology for the 5 target materials and good results have been found regarding energy consumption and KPI´s.

Demonstrator Capacities

- Flexible design (5 materials).
- 30kW at 915MHz.
- Flow Rate: 1-10kg/h.
- Working at High T.
- Continuous Flow.
- Integration of new sensoring.
- SCADA to monitor & control (DDBB).
- Energy Consumption Devices.
- Integration of new applications.
- Environmental parameters.

Figure 8. Demonstrator view.

Examples of products obtained with the Demonstrator´s setup:

Figure 9. Example of glass, frits and slag cement obtained with Demonstrator´s Setup.

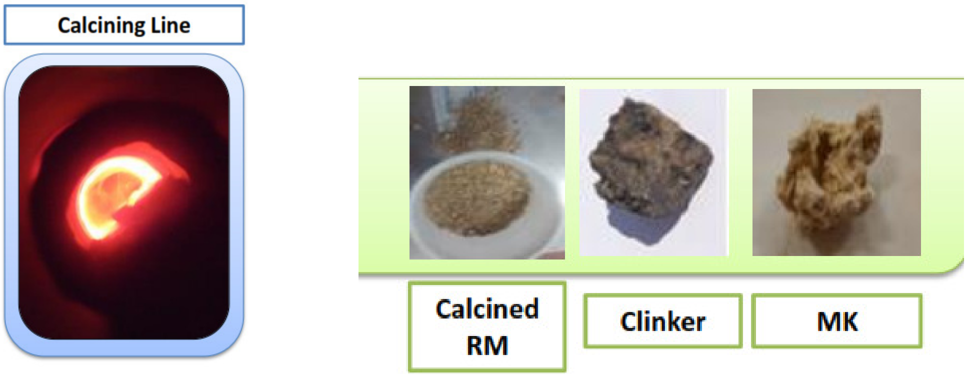

Figure 10. Example of calcines clinker raw meal, clinker and metakaolin obtained with Demonstrator´s Setup

KPIs

MW KPI values were set according to simulations and then validated by operational data, in order to have their reliability enhanced. Moreover, the demonstrator unit was designed and assembled under the objective to achieve enough evidence for the 5 industrial products, even though it should be not considered directly comparable to optimized industrial production lines. As an indicative result, the case of Ceramic Frits is herewith presented.

Figure 11 shows the results for KPI#5 - Specific CO_2 emissions (kgCO_2/tn_frits). When focusing on the direct (on site, "gate-to-gate") emissions (grey bars), the reduction calulated rises up to 81.1%, due to the absence of the combustion of fuels. However, the additional electricity consumption raises the indirect CO_2 emissions (blue bars) by 44%. Nevertheless, the sum leads to a total reduction of 26.7%.

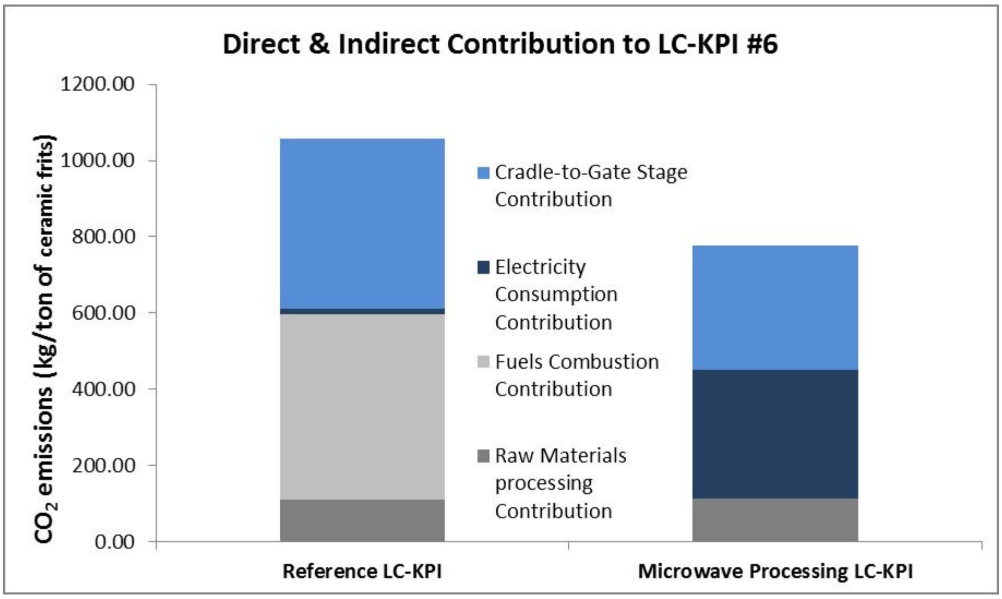

Figure 11. LC - KPI #5 - Reference and MW case values for frits - Direct (grey) and indirect (blue) emissions

An overall conclusion based upon the available data is in order to achieve lower energy costs and CO_2 emissions with the MW process, a 30% of total (fuel + electricity) process energy reduction seems to be necessary

Simulations

Simulations of prototype and demonstrator were performed to study the MW furnace behaviour and the effect of the electromagnetic field on the materials and thermal runaways.

The full simulation of 3D electromagnetic and thermal fields with automatic resonance control should become a current practice to simulate the entire microwave process, including the calculation of the temperature distribution inside the sample, in order to evaluate the scaling-up of high temperature microwave heating. With this methodology the optimum operating conditions for a specific cavity can be found by performing parametric studies. The 3D computational tool allows predicting the evolution towards hot spot formation and with appropriate control and operation conditions to avoid it. The following figures show some results obtained from demonstrator simulations.

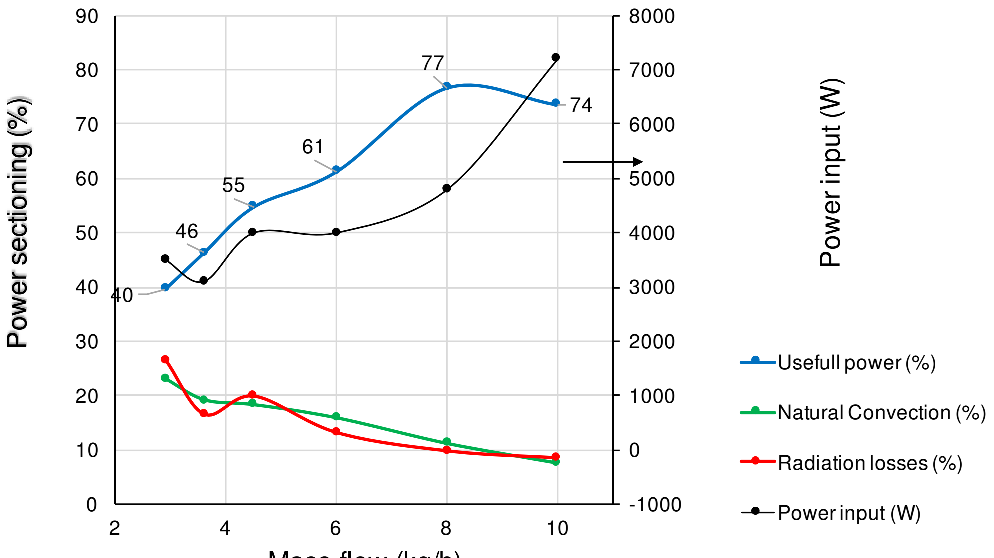

Figure 12. . Influence of the mass flow on power sectioning

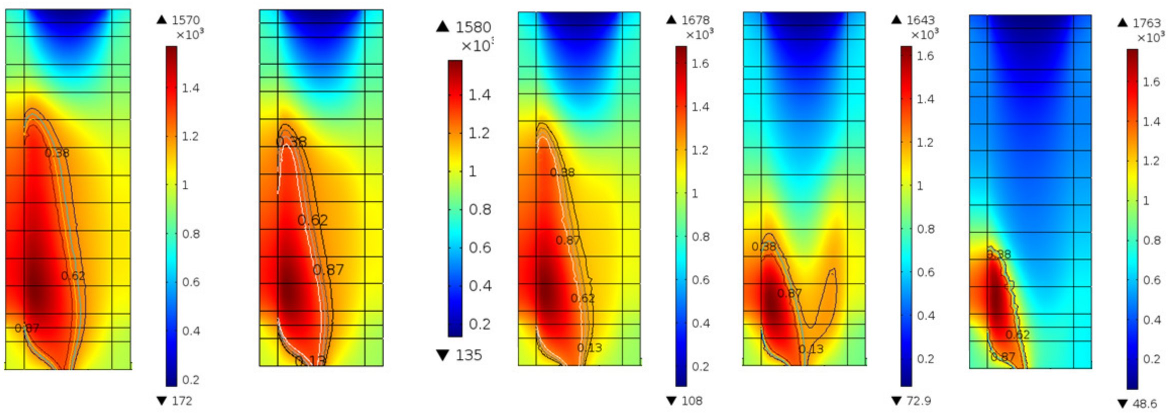

Figure 13. Effect of mass flow on material temperature distribution (molten Mass Flow Rate: 3.6, 4.4, 6, 8 and 10 Kg/h).

LCA and LCC analysis

The environmental profile of MW manufacturing process, of selected materials, has been compared to the Conventional one (CONV). The LCA results revealed that, the introduction of MW heating systems in industrial applications clearly reduces the emissions and the energy consumption in the heating process of building materials.

Basically from the market analysis emerged that cement, glass and ceramic tiles sectors structure is composed by small enterprises with less than 50 employees, among of these companies mostly are micro companies with a number of employees between 1 and 9. Despite the large industrial players are a low percentage in terms of number of enterprises these company generate the most of the European turnover. With reference to the geographic area of interest, Italy and Germany for the end-product manufacturer sectors as well as for the furnace producer results to achieve a top player status; therewith these countries have an already well established market.

The foreground generated by the project will be subjected to two types of exploitation: DAPhNE system as whole as well as single components. The exploitation routes would be targeted on two different markets:

- **Primary markets:** this includes the sectors for which the new technologies have been developed first, i.e. cement, glass and ceramic;
- **Secondary market:** this is the widest market for future exploitation and commercialization (after the end of the project) and includes the manufacturing industry which is energy consuming and where potentially the results of DAPhNE could be technologically transferred.

While both exploitation routes address the primary market, the secondary market is addressed only by the single components exploitation routs.

POTENTIAL IMPACT, DISSEMINATAION ACTIVITIES AND EXPLOITATION OF RESULTS.

Daphne partners have arrived to the commitment to keep on working on the demonstrator three additional months, optimizing processing conditions for five target materials and obtaining more processed samples for validation and characterization.

Expected impacts

DAPhNE has contributed to transform the traditional manufacturing of energy-intensive demand commodities from firing processes, which is based on consumption of fossil fuels with low control process capacity into a completely new concept of flexible, smart and digital factory concept with high efficiency electrical based energy and electronic control.

DAPhNE implementation could have an important contribution for achieving EU policies, particularly the Europe 2020 and the Innovation Union goals, as follows:

- Climatic policies in the Europe 2020 Strategy with the reduction of energy efficiency in more than 40% (as first wave) and long term target and outlines in energy research priorities until 2050. This transformation is basic to be able to cover other initiatives as the Climate and Renewable Energy Package of 2009. It will contribute to interrupt the prevision of emissions of greenhouse gases are expected to increase 2.5 to 3 times by 2050.
- The transformation from DAPhNE into a manufacturing based on electricity energy source with low dependence of fuel-based energy transport, as well as dramatic radical reduction on the total energy demand will help to the European Strategic Energy Technology (SET-plan) and Energy Efficiency Plan 2011. It will be particularly relevant for the energy research priorities, smart energy networks and energy efficiency and saving. Electronic controlled factory will contribute to the management of electricity and more efficient implementation of the technology.
- The less dependence on the quality of the raw materials in some covered processes (i.e. cement industry), the wide applicability to recycled materials (i.e. recycled glass) and a new market of new commodities for susceptors will have strong benefits on raw materials demand, and more indirectly on the transport of raw material. These concepts are collected recently in the document for the European Iniciative Programme of Raw Materials Initiative (EIP-RMI). Widely it is included in Resource-efficient Europe and the Innovation Union Flagship Initiatives from EU 2020, the EU Strategy for Sustainable Development as well as the EC Communication Tackling the challenges in commodity markets on raw materials. DAPhNE, will also contribute to interrupt the trend in the mineral consumption increase by 35-40% expected by 20 years. It will affect particularly to the pillars of: fair and sustainable supply of raw materials from international markets; fostering sustainable supply within the EU; and boosting resource efficiency and promote recycling.
- Reduction and monitoring of KPIs with the new technology implementation will cover air quality in working environment and impact in industrial areas. The objective is in line EU air Quality policies and is in the philosophy of the foreseen revision of EU legislation on Air Quality, which will covered by specific support actions in FP7 and DAPhNE could provide the results and experience.

General exploitation strategy

Microwave heating is now well-established heating technique for industrial sector with low temperature and low power demand processes such as drying. Within DAPhNE project the Microwave Heating Technology will be implemented in three sectors namely ceramic, glass and cement, characterized by high temperature process and high energy consumption. Ceramic, glass and cement sectors still utilize heating system based on traditional natural gas furnaces with very low efficiency and high emission.

Within this chapter is reported the plan for exploiting the foreground generated by the project; this plan includes several elements. Given the involvement of industry as well as of academic partners and research organisations in the project, an appropriate exploitation strategy, to be developed in line with the general rules outlined by the European Commission, must ensure that both industrial and academic interests are appropriately taken into account during the exploitation of the foreground generated by the project.

The exploitation plan of the project results is an update of the Deliverable 7.4 "1st Version of the Exploitation Plan (including IRP Agreement).

This Deliverable was submitted at the end of the project in order to include all outcomes of the project that were not yet measurable and only a provision of the expected outcomes would be possible upon the end of the project.

Exploitation strategy is targeted to specific groups in order to increase the opportunities for the DAPhNE future exploitation strategy.

The main target groups of the DAPhNE exploitation activities can be identified into two categories:

- **Ceramic**, **glass** and **cement** industries as end-users of the high temperature Micro-Wave (MW) technology;
- **Technology manufacturers**.

Ceramic, **glass** and **cement** industries are characterized by energy-intensive demand that still utilize heating system based on traditional natural gas furnaces with very low efficiency and high emission. Therefore these sectors were identified as the end-users of the high temperature Micro-Wave (MW) technology under development within DAPhNE project framework. By implementing the Micro-Wave (MW) technology is expected for the future end-users decrease the CO_2 emissions as well as energy consumptions.

Cement, glass and ceramic sectors structure is composed basically by small enterprises with less than 50 employees, among of these companies mostly are micro companies with a number of employees between 1 and 9. Despite the large industrial players are low percentages in terms of number of enterprises these companies are generating most of the European turnover. **Large industrial players were identified as the most potential customers to introduce the innovative technology** that might have the capabilities to overcome uncertainties and then to implement in their facilities the innovative solution[2].

Another target audience for the DAPhNE project results is characterized by the **future technology manufacturer**. Since heating system for operational high temperature based on the micro wave technology are not available on the market, as future technology manufacturer

[2] Deliverable 7.3 "Market Analysis"

were identified form one side the **traditional manufactures of ovens, furnaces and furnace burners** on the other side the **actual producer of Micro Wave technology**.

The project is industry driven and as such will bring advancements in several industrial areas (see paragraph 2.1) where there would be high interest in commercial exploitations. The existence of positive and realistic perspectives for the commercial exploitation of the project results is clearly highlighted by the major participation of highly qualified industrial partners as well as by the commitment of all partners to the objectives of the research (especially the industrial partners in this respect). This network of partners from the industry already covers the most of the supply chain having the potential to cover all steps needed to bring about the exploitation of the project results towards commercialisation of the DAPhNE system, which clearly indicates the readiness of the established network to engage beyond research.

This is highlight also by the involvement within the project of big players of the cement, glass and ceramic sectors.

The **DAPhNE concept** may be exploited as a **complete system**. The following figure is a description of the supply chain. The supply chain of the innovative technology developed within DAPhNE project has been identified preliminary during the first reporting period [Ref D7.3 "Market Analysis" and D7.4 "1st version of the Exploitation Plan including IPR Agreement"] and updated once the project results were better defined.

Figure 14. DAPhNE supply chain.

DAPhNE network of partners from the industry already covers partially the supply chain having the potential to cover all steps needed to bring about the exploitation of the project results towards commercialisation of the DAPhNE **system as a whole**. The added value of the industrial partnership is that each player is highly qualified and has already a strong position in its respective reference market, with already established commercial channels and clients networks.

Within the project Consortium there are end-product manufacturing for all process formulation developed; these companies are large industrial players that might have the capabilities as Keraben (i.e. Ceramic Frit producer), Cemex (i.e. cement), SB (i.e. glass) and Ascem BV (i.e. Slag). No industrial partner for Metakaolin within the DAPhNE Consortium, despite of this Cemex has shown an interest in the future exploitation of the Metakaolin process based on Micro Wave.

In addition, some **single component** developed within the framework of the DAPhNE Project may also have **own commercial perspectives**. By exploiting the commercial channels and networks each industrial partner is involved in, technologies and system components may be also commercialised independently from the overall complete system provided that ownership of joint developments is appropriately safeguarded.

Some partners may also consider providing **services** related to the project results as exploitation activities such STRESS and NTUA that could provide services related to Life Cycle Assessment and Life Cycle Costing Analysis by using the methodology develop within Project framework.

As academic entities or research organisations NTUA, CSIC-ICV, UPVLC, UNIVPM, TU BAF, IST, AIDICO, FHG as well as CEMEX RESEARCH will not be engaged in any industrial exploitation of the results on the DAPhNE system nor its components, as their interest towards the project is not related to the possibility of exploiting the results for commercial purposes.

Nevertheless, since they are responsible for providing their knowledge during the development of the system and the components, their interest is in the increase in know-how. The know-how that they will acquire during this project will be used mostly for academic interests or for further research activities other than those covered by the project. Though cases may also arise, in which research or academic partners may provide significant support to the development of specific system components or solutions. In that case, agreements with relevant partners will be developed, defining the routes for the joint exploitation of these outcomes.

The following section outlines how the project intends to deal with exploitation. In this framework and exploitation road map was drawn.

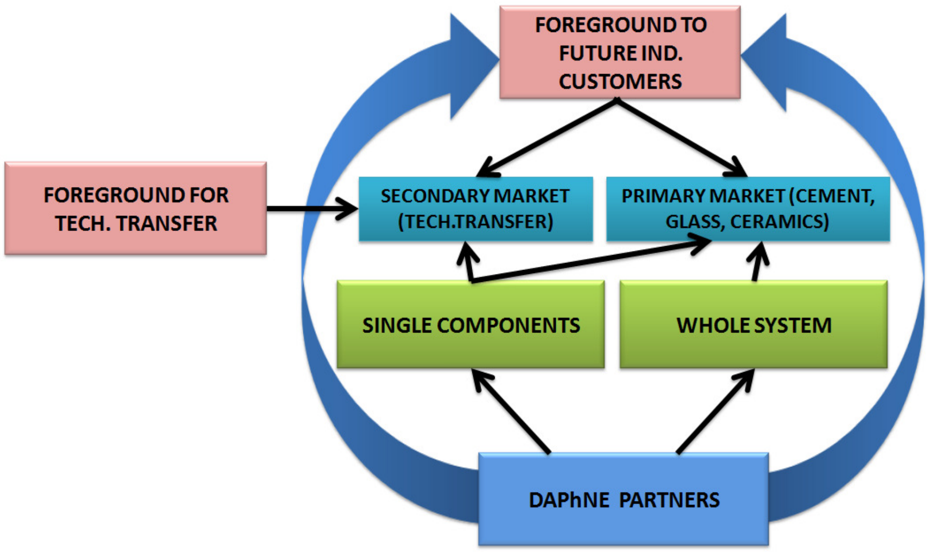

Figure 15. DAPhNE Exploitation Roadmap

The foreground generated by the project will be subjected to two types of exploitation: DAPhNE system as whole as well as single components. The exploitation routes would be targeted on two different markets:

- **Primary markets:** this includes the sectors for which the new technologies have been developed first, i.e. cement, glass and ceramic;
- **Secondary market:** this is the widest market for future exploitation and commercialization (after the end of the project) and includes the manufacturing industry which is energy consuming and where potentially the results of DAPhNE could be technologically transferred.

While both exploitation routes address the primary market, the secondary market is addressed only by the single components exploitation routs.

The original list of the exploitable results (Ref. D7.4) has been revised. A fairly exhaustive list of 14 exploitable results was identified and collectively discussed at the seminar "Self-

Assessment for a balanced and effective exploitation process of DAPhNE innovative results" (11th November 2014, Ancona Italy). This review was necessary since the exploitable results were better improved and discussed deeply at Consortium level when the results have been assessed.

The list below supersedes the list reported within Chapter 2.2, Table 1 within Deliverable 7.4 "1st Version of the Exploitation Plan (including IPR Agreement).

Table 1. DAPhNE Exploitable results

Exploitable Results	Comments	Lead Beneficiary	Beneficiaries Involved
1) Energy Efficiency and KPI Management services	Simulation software for process design and optimization.	FhG-IPA	FhG-IPA, TU BAF, NTUA, IST, STRESS
2) Susceptors for microwave heating	Special formulation. Might be patented	CSIC-ICV	CSIC-ICV, CEINNMAT, UPVLC
3) Microwave applicator and filtering	Critical component where MWs meet and heat materials	CEINNMAT	CEINNMAT, UPVLC, CEMEX CRG
4) Microwave generator with extra short response time.	Improvement of existing generator to meet DAPhNE requirements	MUEGGE	MUEGGE
5a) Innovative methodology for real time monitoring of kilns	Methodology or special probe	CEINNMAT	FLO-IR, CEINNMAT, UNIVPM, IST
5b) Virtual Sensors for indirect measurement of inner temperature in kilns	SW elaborating data from process sensors to determine indirectly kiln temperatures	UNIVPM	UNIVPM, CEMEX CRG, IST
6) Adaptive control system for MW heating	Might include a database for self-learning	CEINNMAT	CEINNMAT, TR, UPVLC, UNIVPM, FhG-IPA, MUEGGE
7a) Complete system for "calcination" based on HT MW Heating system	Integration of components in a way that will fit the production lines	TR	TR, CEINNMAT, UPVLC, CEMEX CRG, CEMEX C, TU BAF, IST
7b) Complete system for "melting" based on HT MW Heating system	Integration of components in a way that will fit to the production lines	TR	TR, CEINNMAT, UPVLC, CEMEX CRG, CEMEX C, TU BAF, SB, IST, KERABEN

Exploitable Results	Comments	Lead Beneficiary	Beneficiaries Involved
8) Process for Ceramic frit based on MW heating system	Reduce substantially the use of energy and reduce significantly processing time. End product quality could benefit from MW	KERABEN	KERABEN, CEINNMAT, UPVLC, IST
9) Process for Slag cement based on MW heating system	Reduce substantially the use of energy and reduce significantly processing time. End product quality could benefit from MW	ASCEM	ASCEM, CEINNMAT, UPVLC, IST
10) Process for Portland clinker based on MW heating system	Reduce substantially the use of energy and reduce significantly processing time. End product quality could benefit from MW	CEMEX CRG	CEMEX CRG, CEMEXC, CEINNMAT, UPVLC, IST
11) Process for Glass based on MW heating system	Reduce substantially the use of energy and reduce significantly processing time. End product quality could benefit from MW	SB	SB, CEINNMAT, UPVLC, IST
12) Process for Metakaolin based on MW heating system	Reduce substantially the use of energy and reduce significantly processing time. End product quality could benefit from MW	CEMEX	CEMEX, CEINNMAT, UPVLC, IST

In order to have a clear strategy for securing and managing newly generated know-how as well as regulate the DAPhNE partner ownership, a protection plan for each exploitable result was developed during the implementation of the DAPhNE process. The protection plan of the exploitable results is reflected and taken into account within the development of the individual exploitation plan for each partner.

Exploitable results	Responsible partner	Protection Plan
1) Energy Efficiency and KPI Management services	FhG-IPA	Exploitation Agreement after the end of the project
2) Susceptors for microwave heating	CSIC-ICV	Patent application under elaboration
3) Microwave applicator and filtering	CEINNMAT	Patent application under elaboration
4) Microwave generator with extra short response time.	MUEGGE	Trade secret

Exploitable results	Responsible partner	Protection Plan
5a) Innovative methodology for real time monitoring of kilns	CEINMAT	Protection by patent could be explored. Licensing.
5b) Virtual Sensors for indirect measurement of inner temperature in kilns	UNIVPM	Exploitation agreement after the end of the project
6) Adaptive control system for MW heating	CEINNMAT	Patenting will be explored before the end of the project.
7a) Complete system for "calcination" based on HT MW Heating system	TR	Process license developed individually or in partnership with other members
7b) Complete system for "melting" based on HT MW Heating system	TR	Process license developed individually or in partnership with other members.
8) Process for Ceramic frit based on MW heating system	KERABEN	Patent application under elaboration
9) Process for Slag cement based on MW heating system	ASCEM	Trade secret. Patenting parts of it will be explored
10) Process for Portland clinker based on MW heating system	CEMEX CRG	Trade secret. Patenting parts of it will be explored
11) Process for Glass based on MW heating system	SB	Trade secret. It will be patented if potential of selling the applicator for conventional glass furnaces to competitors in the glass processing industry is observed.
12) Process for Metakaolin based on MW heating system	CEMEC CRG	A patent was filed

Clustering

First activities conducted in this sense were connected with the IMS (Intelligent Manufacturing Systems) program. The signature of the Memorandum of the Agreement formalized the integration in the IMS. The sponsoring by IMS allows the DAPhNE's project to have access to the MTP platform (Manufacturing Technology Platform) which is in charge of sustainable manufacturing, energy efficiency, key technologies, standards and interoperability, and education and safety.

KERABEN and UNIVPM have participated on several events as workshops and dissemination activities, in many cases preparing and using specific dissemination elements like PowerPoint presentations, banner posters, leaflets, etc. An example of this is the World Manufacturing Forum organized by IMS in Milan during 1st and 2nd of July in 2014. For further details, refer to the dissemination list.

Another important activity consisted on CLUSTERING with other similar EU projects due to their inter-linking with existing technology transfer activities, are effective ways to stimulate the take-up of project results and to exploit synergies.

The first approach was setting up a concrete and operative clustering action, among those EU projects that deal with improvement of energy efficiency in manufacturing thanks to energy recovery technologies in their most general acceptation, both at hardware and software level.

This initially gathered 4 projects:

- FACTORY-ECOMATION (http://www.semanticweb.it/factory-ecomation)
- REEMAIN (http://www.reemain.eu)
- FOUNDENERGY (http://www.foundenergy.eu)
- DAPhNE (http://daphne-project.eu).

In the first meetings, the idea was to discuss openly about: identification of technical synergies of the projects involved; selection of partners that could contribute (and benefit) from the Cluster; pillars for the definition of an inter-consortium NDA; concrete activities to make the Cluster really useful (technical workshops among partners, sharing of end-users requirements/constraints, joint dissemination events, etc.).

A brief overview of each project was provided to the project coordinators, with particular reference to subjects relevant for the clustering. An excel file was filled in for identifying technical contents that could leverage on clustering activity to maximize exploitation of results (technical synergies, partnership in industrialization/commercialization, end-user for further experimentation, etc.). Such operation was performed in order to facilitate a pre-selection of partners that could be interested/benefit/contribute directly to the clustering.

The members of this first cluster were invited to enter in the CLEAN MANUFACTURE cluster. Apart from DAPhNE, FOUNDENERGY, REEMAIn and FACTORY-ECOMATION, the CLEAN MANUFACTURE cluster involves the following projects:

- EMC2 (www.emc2-factory.eu)
- ENEPLAN (www.eneplan.eu)
- REFORM (www.reform.eu.com)
- AREUS (www.areus-project.eu)

The projects in CLEAN MANUFACTURE are working together to reduce waste and improve efficiency at all levels of the factory, from individual machines to the whole facility. Coordinators of all 8 projects are in contact, and have collaborated preparing the FoF Workshop that took place on 29th April 2015 under the 'Advanced Manufacturing Processes: EcoFactories' area. Scientific/technical goals of the supported area were compared, and it was discussed about Current and Expected impacts, and synergies and benefits of clustering.

DAPhNE is also collaborating with the CSA ‘EFFECTIVE’ (Exploiting Factory of the Future projects through Enhanced Clustering towards technology Transfer, Innovation and Value creation for European industry.) EFFECTIVE is a Coordination and Support Action aimed at fostering and enhancing the active clustering of activities and results of FoF Projects in order to maximise their exploitation. DAPhNE was invited to participate in the 1st EFFECTIVE workshop “Paving the way to effective clustering towards exploitation & dissemination of FoF projects results” that took place in Lomazzo (IT) on 1-2 July 2015.

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