PROJECT FINAL REPORT

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Project acronym: REBIOFOAM

Project title: Development of a flexible and energy-efficient pressurised microwave heating process to produce 3D-shaped Renewable BIO-polymer FOAMs for a novel generation of transportation packaging

Funding Scheme: Collaborative Project (targeted to a special groups such as SMEs)

Period covered: From the 1st February 2009 to the 31st January 2013

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Final publishable summary report

Executive summary

The ReBioFoam project (Development of a flexible and energy-efficient pressurised microwave heating process to produce 3D-shaped Renewable BIO-polymer FOAMs for a novel generation of transportation packaging) was a large-scale collaborative project within the EU's 7th Framework Programme. This four year project started on February 1, 2009, and had a total budget of 5,1 million Euro of which the funding from the European Commission was 3,5 million Euro. The overall aim of the project was to develop a flexible and energy-efficient pressurised microwave heating process to produce 3D-shaped Renewable BIO-polymer FOAMs for a novel generation of transportation packaging. The ReBioFoam project has generated a lot of interesting results. Here follows a list of the most important results:

1) The materials formulation has been defined as well as the process parameters for **pellets** production; the pellets produced at semi industrial level have proved having good homogeneity, proper water content and morphology and defined chemical physical properties both at the pellets and at the foamed material level.

2) A flexible and energy-efficient **microwave heating process** to produce 3D-shaped items has been defined and implemented toward the realization of a continuous process line at the semi industrial level. Particular focus was given to mould development as well as to microwave cavity design, which also included optimization of the inside field homogeneity.

3) Key features of the **mould** which enhance product properties have been identified; smooth surface and hot surface led to the production of a prototype mould which provided good quality, low density products and to the development of a good understanding of doping mechanisms and mould design.

4) **Microwave cavity** design, along with inside field homogeneity, were optimized by test productions of prototypes, expansion tests and the simulation of microwave fields into several designs of cavities. This led to the definition of the optimal and most energy-efficient microwave cavity solution and to the production of items with density of 40-50 kg/m^3.

5) The possibility to reach the target density even at low pressure implied a significant advantage for the project particularly as regards the exploitation potential of the technology, while not implying any change to the original goal and objective of the project thanks to the obtainment of a more scalable and easy way to obtain the envisaged foam products at a semi-industrial scale.

6) Two **demonstrators** were selected, defined and realized: a port hole spacer for washing machines and a corner for packaging application. The target density of 40-50 kg/m^3 was reached for both, their properties were analysed and results pointed out the good physic-mechanical behaviour of the new ReBioFoam packaging design, also in comparison to EPS material, which was used as reference. Ambient performances are better for the most important impact categories. Moreover, the product is biodegradable and compostable in home and industrial conditions.

7) A fully automated semi-industrial pilot line has been developed, which is able to produce foamed samples with density 40-45 kg/m^3.

Summary description of project context and objectives

The ReBioFoam project (Development of a flexible and energy-efficient pressurised microwave heating process to produce 3D-shaped Renewable BIO-polymer FOAMs for a novel generation of transportation packaging) was a large-scale collaborative project within the EU's 7th Framework Programme. This four year project started on February 1, 2009, and had a total budget of 5,1 million Euro of which the funding from the European Commission was 3,5 million Euro. The overall aim of the project was to develop a flexible and energy-efficient pressurised microwave heating process to produce 3D-shaped Renewable BIO-polymer FOAMs for a novel generation of transportation packaging. This was the project logotype:

Figure 1 – ReBioFoam's logo

Context

Each year, millions of tons of protective packaging waste are generated throughout Europe and worldwide. Protective packaging generally consists of shape moulded resin parts used as impact cushioning shields to preserve and protect products from damage as they are moved within or between facilities, or shipped to their final destination. Expanded polystyrene polyurethane , polyethylene and polypropylene are the most popular cushioning materials applied for protective packaging applications. Despite of their functionality, the widespread use of these polymer foams of synthetic origin implies considerable environmental concerns. The depletion of non-renewable fossil raw material resources, associated with emissions of greenhouse gases (such as C_5H_{12} and CO_2, which are applied as blowing agents during the foaming process), are the most direct impacts on the environment. Moreover, their non-biodegradable/ non-compostable nature, associated with the short life of protective packaging products, rises up fundamental concerns regarding waste disposal. Recycling, which is the solely applicable solution for preventing those synthetic foams entering the waste stream, appears in fact to be not always applied due to cost-ineffectiveness.

With this in mind, biodegradable and compostable bio-based plastics represent an emerging highly promising solution for protective packaging provided that they can be processed in foamed products resulting in adequate functional requirements.

Project objectives

The REBIOFOAM project targeted the development of a biodegradable REnewable BIO-polymer FOAM to be applied as protective packaging material. To this end, the project aimed at developing a new environmentally-sustainable manufacturing process for the production of foamed 3D-shaped packaging material originating from expandable starch-based polymer pellets. In this new process, expansion of the pellets is driven by microwave technology and exploits the inner water content of the material to generate vapour at high pressure, which triggers the foaming process. The REBIOFOAM process is a multiple step process, consisting of the following steps:

1) Formulation and processing: the base materials, i.e. mainly starch and water, are processed with smaller quantities of other required bio-based additives.
2) Extrusion and pelletizing: the material is extruded into controlled morphology pellets of well defined water content; this, combined with subsequent conditioning, allows achieving tailor made chemical and physical properties of pellets as required for the expansion.
3) Microwave-assisted expansion and moulding: pellets are transferred into a microwave transparent mould and are further processed in a microwave environment with controlled temperature and pressure conditions. Rapid dielectric heating of the pellets to a temperature beyond the flash point of the blowing agent, which is the inner contained water, causes the pellets to foam in the mould thus resulting in a 3D-shaped foamed product.

The development of such a process involved three fundamental development steps. On the one side, a microwave expandable material had to be developed through proper formulation and processing of the base materials, thus allowing to achieve, at the end, moulded foam products meeting functional requirements for protective packaging.

On the other side, a heating / expansion system had to be developed, applying microwaves to achieve adequate foaming of the bio-based polymer, to be described in terms of expanded cell's size and conformation/shape, cell's morphology, and, finally, mechanical characteristics and cushion behaviour of the expanded samples. This implied carefully evaluating effects of microwave fields as well as varying temperature profiles, and achieving an efficient design of the microwave oven as well as efficient tuning of the operational parameters required for the expansion.

Last but not least, adequate mould design had to be accomplished for successful processing of moulded, 3D-shaped, foam products. To this extent, a thorough comparison of dielectric properties of mould materials as well as a careful selection of the most appropriate material for mould construction, guaranteeing proper adhesion to the substrate while achieving at the same time inherent surface temperature control, had to be achieved. At the same time, the occurrence of viscous shear stresses at the foam / mould interface had to be minimized, thus facilitating complex 3D shaping during the moulding process, through the proper design of the mould surface. Following the achievement of the abovementioned partial objectives, the goal was to develop an automated pilot plant prototype demonstrating viability of technologies at a larger semi-industrial scale. The pilot plant had to be subsequently used to produce foamed protective packaging product prototypes for different applications by responding to requirements of the End-Users involved in the project. Those foamed protective packaging products had to be subject to standard performance tests for cushion packaging materials such as compression as well as compressive creep strain tests according to ASTM D3575-08, transmissibility tests according to BS EN ISO 13753, dynamic shock cushioning tests according to ASTM D1596, etc. Furthermore, biodegradability and compostability had to be also evaluated according to EN 13432, "Requirements for packaging recoverable through composting and biodegradation - Test scheme and evaluation criteria for the final acceptance of packaging", providing presumption of conformity with the European Directive 94/62 EC on packaging and packaging waste. Biodegradation and disintegration tests had to be carried out as well according to ISO 14851 and EN 14045 respectively. Particularly, according to Annex I, the following scientific and technical objectives had to be addressed:

- To develop a proper formulation and proper processing of base materials thus allowing to achieve moulded foam products meeting functional requirements for transport packaging.
- To define relationships existing between the formation of the pellets' morphology, and the extruder design and extrusion process parameters to be defined as well.
- To establish a comprehensive scientific understanding of the role played by the pellet's physic-chemical characteristics with respect to pellets expansion rate.

- To study pellets post-conditioning and subsequent handling conditions in order to ensure proper expansion of the pellets also after handling and storage.
- To evaluate effects of microwave fields and varying temperature and pressure profiles on the rate of moisture loss, indicating moisture retention capability, during microwave heating, thus enabling an efficient design of the microwave oven as well as efficient tuning of operational parameters required for expansion. To compare dielectric properties of different mould materials as well as to select the most appropriate material for mould coating guaranteeing proper adhesion to the substrate while achieving at the same time inherent surface temperature control, in order to enable efficient transmission of microwave energy thus allowing rapid and uniform heating at the field intensity required for expansion.
- To minimize the occurrence of viscous shear stresses at the foam / mould interface thus facilitating complex 3D-shaping during the moulding process through the development of an appropriate mould surface coating treatment and to investigate bonding between coating and mould under cyclic loading conditions, in order to maximize its durability.
- To develop an efficient microwave moulding system with variable pressure control up to 10 bar, including a proper design of the microwave transparent tooling as well as an efficient design of the microwave cavity, thus achieving uniformity of heating within the mould and a consequent uniformity of foam properties.
- To extensively characterize foam samples in what concerns both static and dynamic properties such as compressive strength, creep and cushion behaviours, G factor curves, and to elaborate cushioning curves for different foam types obtained by varying both material as well as operational parameters towards designing new foam packaging applications.

Description of the main S&T results / foregrounds

Project structure and approach

The REBIOFOAM project aimed at introducing a flexible and energy-efficient pressurised microwave heating process to produce 3D-shaped Renewable BIO-polymer FOAMs for a novel generation of transportation packaging through an innovative concept that is constituted by:

1) A new IDEA: foaming an innovative starch-based material using MicroWave technology, exploiting the inner water content of the material to generate vapour at high pressure, which triggers the foaming process;
2) New PROCESS: validating a new process for the production of a defined 3D-shaped demonstrator using a semi-industrial pilot line developed within the project;
3) New PRODUCT: achieving a biodegradable and compostable product, having good environmental performances and cushioning properties.

To this purpose, the project has been executed in the following interconnected work packages, as illustrated in Figure 2.

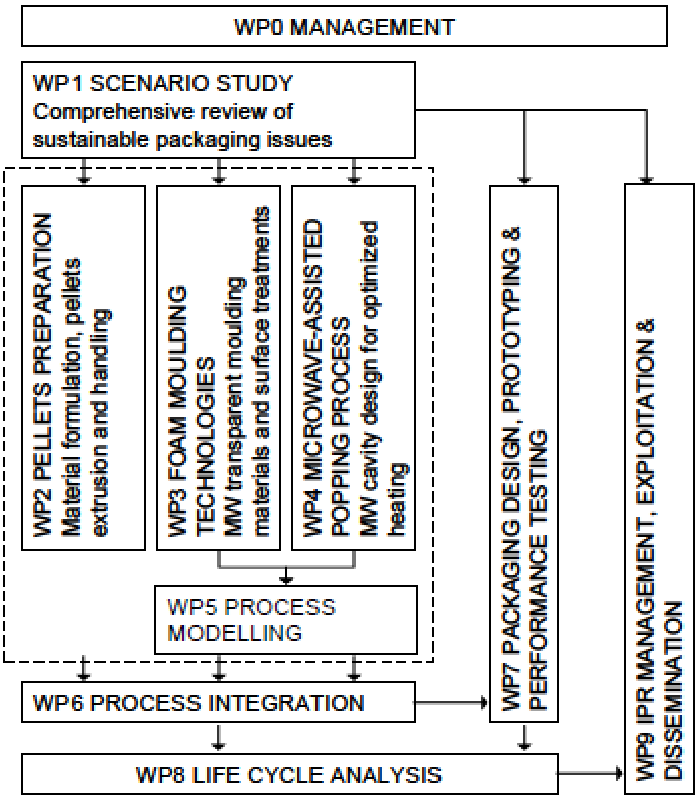

Figure 2 – Pert diagram

WP1 aimed at analysing the current scenario of protective packaging materials, related manufacturing processes, and markets, in order to set high-level guidelines for the development of the new technology. WP2 focused on studying the receipt, and on developing the extrusion process, in order to achieve adequate physic-chemical characteristics of the pellets to enable smooth expansion of the biopolymer in a subsequent processing step. WP3 targeted the development of appropriate foam moulding technologies through the selection of proper mould materials as well as the definition of appropriate moulding conditions. WP4 focused on the development of the microwave-assisted expansion process, being also assisted by modeling approaches to optimize operational parameters (WP5). Last but not least, WP6 was dedicated to the integration of the above technologies into a pilot process, while WP7 targeted the demonstration of the technology through the prototyping of 3D-shaped moulded bio-polymer foam parts as well as their testing according to standard tests for cushioning materials. Life Cycle Analysis complemented research activities in WP8, allowing to analyze the cradle-to-grave cycle of bio-based transport packaging products. Last but not least, WP9 dedicated to IPR management, exploitation and dissemination activities, while WP0 dedicated to Management activities.

The following sections are aimed at summarizing main achievements of each WP.

WP1 SCENARIO STUDY

WP1 aimed at analysing the scenario (i.e. by particularly analysing the relevant legislation and the market) and at setting an overall guideline for the design and development of the biodegradable foamed 3D-shaped packaging from the biopolymers to be developed (i.e. by identifying the technical and functional properties that the packaging should have).

Accordingly, activities started with an extensive analysis of the legislative framework that the ReBioFoam project should take into account in developing a technology and a product in compliance with the current scenario. Moreover, a market review was accomplished in order to identify a market framework in which the new product should be introduced. The current market for cushion and transport packaging is, in fact, dominated by certain technologies with which the new product will inevitably compete. In Figure 3 the worldwide market trends of foamed polystyrene for protective packaging (2004-2014) in Mln US $ is presented (Source: INSEAD, 2008).

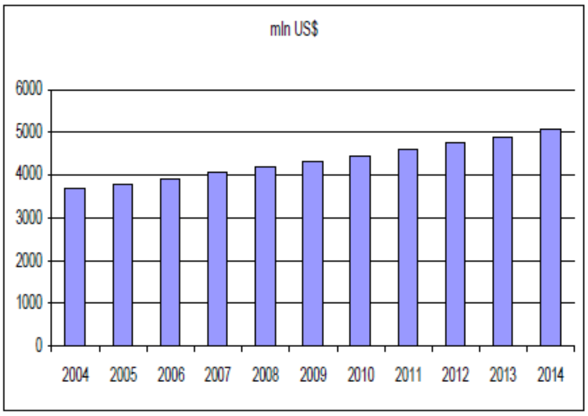

Figure 3 The worldwide market trends of foamed polystyrene for protective packaging (2004-2014)

Moreover, within WP1, the Consortium partners helped in defining a project demonstrator that is a porthole spacer (Figure 4), actually made of EPS and having a foam density of 20-22 kg/m^3, which is manually inserted between the washing machine and the drum and whose main function is to block and stabilize the washing group during the transport of the appliance, avoiding unwanted vibrations and consequent damages to the washing group, before the arrival of the washing machine at the customer site. The choice of the demonstrator was mainly based on the following criteria:

- the shape of the selected demonstrator is complex enough to be used to evaluate the ability of the foamed biopolymer to fill the mould;
- the mould dimension is big enough to be manufactured in a semi-industrial equipment and tested at semi-laboratory scale;

- from the industrial exploitation point of view, the selected demonstrator could already have a good potential in the market.

Figure 4 - Porthole spacers made of EPS, selected as the demonstrator of the project

Furthermore, in order to evaluate the flexibility of the technology, the possibility to develop other packaging system prototypes with specific shapes (i.e. box, corner protection) has been investigated as well during the project and the production of a further packaging system prototype, that is a corner protection, has been implemented within Novamont's microwave pilot plant.

WP2 PELLETS PREPARATION

The main achievements for this WP were the definition of a proper material formulation, and of the process at laboratory and semi-industrial level able to produce pellets with the required physic and chemical characteristics to be foamed by a flexible and energy-efficient microwave heating process to produce 3D-shaped items. Accordingly, the following achievements can be highlighted on the pellets:

- The optimal water content has been defined and is achieved after a drying phase;
- The morphology has been optimized towards the maximum level of foaming and a proper outer skin has been obtained to maximize the flash foaming;
- A shelf life of up to 3 months has been achieved.

Furthermore pellets and the raw materials were analyzed in term of:

- Determination of the cristallinity percentage;
- Molecular weight;
- Foaming capacity of aged pellets.

With respect to the latter point, aged pellets still have a good foaming capacity and mechanical properties comparable to the fresh pellets. The pellets foaming capacity was evaluated modifying the MW power profile and measuring the temperature within the pellets and the consequent foamed product diameter (Figure 5). The general consideration is that the maximum MW power has to be irradiated on the pellets.

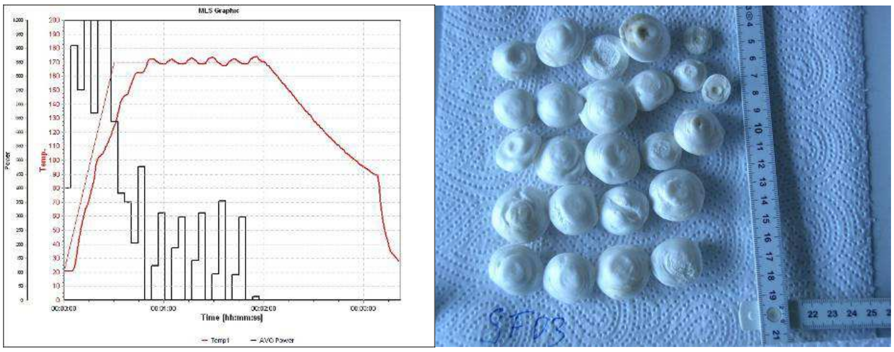

Figure 5 - Experimental test: left, in black: the MW power; in red: the temperature profile (real and set); right: the foamed pellets

Within WP2 it was also ultimately possible to demonstrate the feasibility of producing pellets at semi-industrial level; pellets were produced continuously and pellets storage was simulated in order to confirm the possibility to transport and use the new pellets as traditional ones (Figure 6). Furthermore, the semi-industrial pilot production line was designed as a scale down of an industrial one, thus confirming industrial feasibility up to a production capacity of 1000 kg/h.

Figure 6 - ReBioFoam starch-based pellets

WP3 FOAM MOULDING TECHNOLOGIES

WP3 aimed initially at evaluating materials suitability for use in moulds to be applied within the ReBioFoam process as well as at evaluating approaches for mould surface treatment so as to achieve a heated surface and a smooth mould release. Subsequently, the objective was to design and make prototype moulds for the pilot production of porthole spacer demonstrator samples by which to carry out expansion trials.

Accordingly, the main properties required to the MW transparent mould were defined. Different materials were analysed, and several designs were studied to optimize the specific properties of the foamed product samples.

Surface treatments in order to prevent the collapsing of the foamed item surface (caused by the presence of water) were evaluated as well as different methods were tested. Results achieved at lab scale led to a smooth surface of the foamed product.

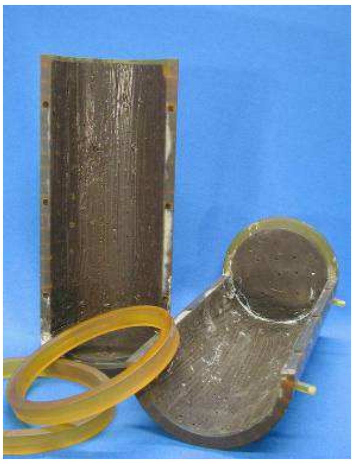

Figure 7 - Mould prototype

Starting from the R&D results and with the aim to scale up the results obtained at the lab scale, different approaches were evaluated such as paints and/or surface treatments. Results demonstrated that, from an industrial point of view, heating of the mould by conventional (e.g. IR) methods was the best choice, furthermore considering that, during the process, heating is only necessary in the start up phase.

Another important result was the definition of the mould structure for the pilot line the best solution was to use two different materials combined in order to guarantee the mould mechanical and thermal performances with the flow capacity of pellets on the mould surface.

WP4 MICROWAVE-ASSISTED PRESSURIZED EXPANSION PROCESS

The main objectives of WP4 were to design and build a small-scale prototype microwave system to be verified by testing and the characterization of foamed product items, thus identifying key parameters for the development of the semi-industrial MW system in WP6.

The initial work was related to the realization of a pressurized MW oven to guarantee the required foaming capacity and the field homogeneity within the cavity. This equipment allowed to obtain a foamed product that respected targets and expectations.

The continuous upgrade of pellets properties and their foaming capacity allowed to reach comparable results at both low and high pressure conditions. This important result allowed to simplify the production process as well as the pilot line concept and design.

WP5 PROCESS MODELLING

The objectives of WP5 were the design and optimization of a microwave applicator/chamber for the microwave assisted pressurized heating of bio-based plastics as well as the process simulation towards the optimisation of the process parameters.

Activities were focused on the simulations of microwave fields in different cavities and then of pellets behavior within different cavities and microwave fields. The first step was the definition of the dielectric properties of the pellets and mould. The simulations were carried out considering different oven designs and considering different positions of the mould within the cavity. As shown in Figure 8, which shows simulated results of the variation of the electric field strength at different mould positions in the MW oven, mould rotation allows to achieve a better distribution of the electromagnetic field. For this reason a rotating table was suggested for the pilot line.

Furthermore an equipment to measure the temperature of the pellets surface during foaming was set up. An IR camera was fixed near the pellets in an open resonator. Information related to the surface temperature of the pellets during foaming was analyzed and compared to results of WP2 (Figure 9).

As a general consideration, the temperature on the pellets surface is higher than 100°C, suggesting the presence of pressurized steam within the pellets.

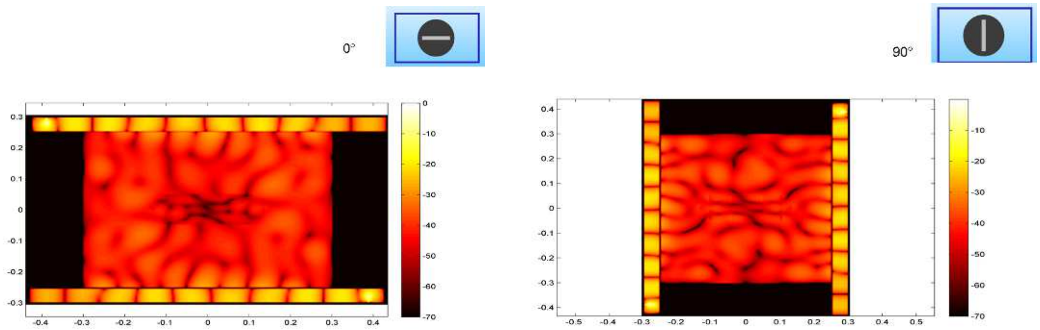

Figure 8 - Variation of electric field strength [dB] at different positions in MW oven (0° and 90°)

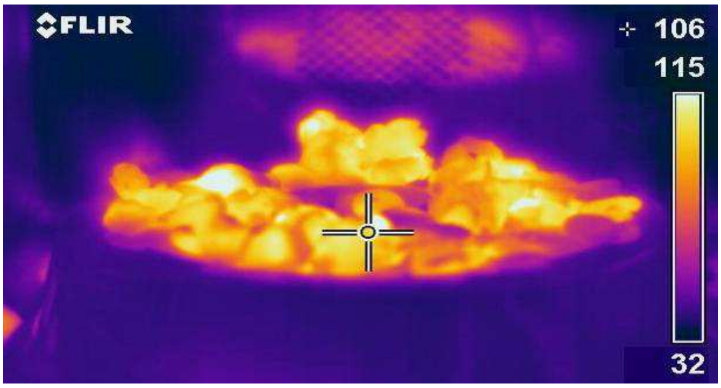

Figure 9 - Equipment to measure the temperature on pellets surface using a IR camera (left) and the pellets during the foaming (right)

WP6 PROCESS INTEGRATION

Main objectives of WP6 were the initial definition of high-level production requirements and the setting of high-level specifications guiding the development of the key steps in the pilot semi-industrial process. Accordingly, detailed technical specifications had to be defined for the semi-industrial pilot process and an automated semi-industrial pilot line had to be designed and developed.

Within this framework, the pilot line design was defined in parallel and taking into account R&D activities carried out within the other WPs. The decision, thanks to the upgrade of the pellets properties and the optimization of the foaming process, to move from a pressurized system to a low pressure microwave process line gave several advantages, i.e. the improvement in flexibility, scalability and energy efficiency as well as a reduction in cost. The pilot line was defined, which consists of the following processing units:

1) Storage and dosing unit of the bio-polymeric pellets with correct amount of water;
2) Foaming process of the pellets inside the microwave system;
3) Extraction stage of the foamed product;
4) Conditioning unit of the bottom half mould.

Accordingly, bio-polymeric pellets with a specific water content are dosed properly in the mould, which is then transferred to the MW system. In this stage the mould is closed mechanically and MW irradiation is started up, so that pellets can foam inside the mould, releasing steam. The mould is brought out from the oven and transferred to the extraction unit, in which the foamed product is extracted by two extractors and one manipulator. Only the mould is transferred to the conditioning unit where it is conditioned thermally before restarting a new process cycle.

The resulting pilot line is a semi-automatic rotary machine endowed with a central shaft able to turn around a main table. On this table four plates are jointly installed, and on each plate there is installed only one mould. The central table is able to turn around in order to transfer each plate supporting the mould from a station to another one.

A 3D model of the assembled pilot line is represented below (Figure 10).

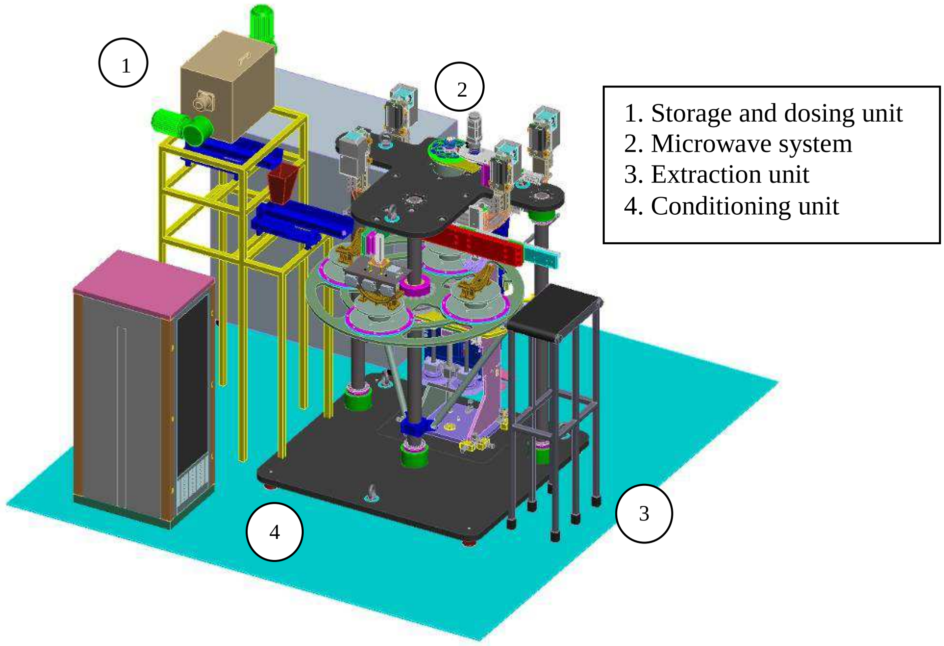

Figure 10 – 3D model of the assembled pilot line

The line is completely automatic, and human interaction is minimal. Moreover, the foamed samples obtained by the pilot line have densities comparable to samples coming from the laboratory (i.e. 40-45 kg/m^3).

WP7 PACKAGING DESIGN, PROTOTYPING AND PERFORMANCES TESTING

The main activities of this WP were related to the definition of the properties of the new foamed material. An extensive characterization work was thus carried out in terms of mechanical and thermal analysis, test in use, determination of the cells structure of the foam and evaluation of the biodegradability according to the standard. Accordingly, prototyping trials of expanded foam package systems had to be carried out by means of the semi-industrial process line and the mechanical performances and cushion behaviours of the package system prototypes produced by means of the semi-industrial line had to be characterized, along with porosity and BET sorption.

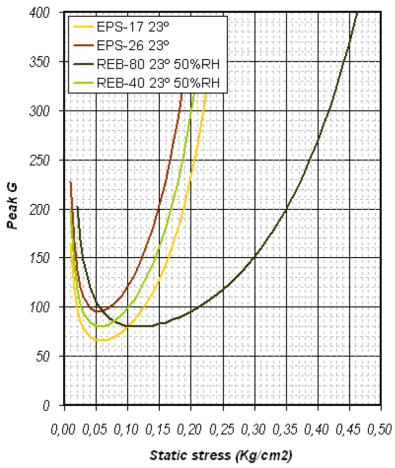

Figure 11 – Dynamic shock cushioning characteristics (based on ASTM D1596) of ReBioFoam material (40 and 80 kg/m^3) and EPS (17 and 26 kg/m^3)

In particular, foam samples of different densities were tested and compared to EPS. Some of the results are shown in the picture above (Figure 11), from which it is evident that, as regards Dynamic Shock Cushioning characteristics (based on ASTM D1596), the ReBioFoam material (with density 80 kg/m^3) performs better than EPS, whereas the new foamed material with lower density (40 kg/m^3) is comparable to EPS. The same result was achieved for the other tests performed, which comprised:

- Test method to obtain the material thermal resistance (internal procedure based on ISO 8894-1);
- Standard test method for thermal insulation quality of packages (internal ITENE procedure);
- Test method for rubber property - Volume Resistivity of electrically conductive and antistatic products (based on ASTM D991-89);
- Evaluation of the Compression Stress (based on ASTM D3575-08);
- Evaluation of the Compression Creep Strain (based on ASTM D3575-08);
- Evaluation of the Trasmissibility (based on BS EN ISO 13753:2008);
- Evaluation of the Dynamic Shock Cushioning Characteristic (based on ASTM D1596).

The foamed prototypes were also analyzed according to Electrolux packaging tests specifications for fabric care products. In Figure 12, the porthole spacer demonstrator is placed within a washing machine, exerting the same performances of the one of EPS.

Figure 12 - The REBIOFOAM porthole spacer demonstrator placed within a washing machine (the external packaging (left) is in EPS)

A second demonstrator was realized as well at laboratory level, in order to demonstrate the protective performances of the new foamed material. This prototype is a corner that can be used in different applications, and whose innovation lies in the possibility to modify its surface area considering the material properties and the product to be protected. This new ReBioFoam packaging system prototype behaviour was compared with the behaviour of EPS packaging, doing the same tests with the original washing machine packaging. The test plan included the following steps:

1) Climatic conditioning for testing;
2) Drop test;
3) Compression test;
4) Vibration test;
5) Stability test;
6) Rotational drop test;
7) Horizontal impact test.

The obtained results indicate a good physic-mechanical behaviour of the new ReBioFoam packaging design. Moreover, if the actual EPS packaging is compared with ReBioFoam packaging, the different levels of the acceleration curves obtained from the tests show that ReBioFoam packaging is able to absorb more energy thus showing enhanced protection capability than EPS protection.

Finally, biodegradability and compostability of ReBioFoam items were tested according to standard EN13432 that requires:

1) Biodegradability;
2) Disintegration during biological treatment;
3) Absence of negative effects on the composting process;
4) Absence of negative effects on the quality of the resulting compost.

Results pointed out that Rebiofoam material complies with the EN13432 requirements. Furthermore, disintegration test in Home Composting conditions (according to UNI 11355) was carried out confirming that the product is not only compostable at industrial conditions, but also in home composting (Figure 13) and recycling test of paper/cardboard was carried out as well pointing out that the materials could be recycled with paper/cardboard without interfering with the pulp recycling process.

Figure 13 - The porthole spacer before and after disintegration in home composting conditions

WP8 LIFE CYCLE ANALYSIS

The objectives of WP8 were to analyse the cradle-to-grave cycle of bio-based transport packaging products, and to compare results with environmental impacts procured by competing technologies such as EPS. Moreover, a Business Model involving all players composing the Value Chain had to be developed in close cooperation with exploitation activities (WP9).

Relevant activities have concerned the development of the LCA model following the framework of LCA. The model has been continuously improved with more complete, representative data about raw materials, REBIOFOAM expansion processes etc. whenever they were available from partners. A methodological overview and related activities are summarised in Figure 14.

The Functional Unit (F.U.) of the study was defined as “the production, use and disposal of 100 porthole spacers”. All the main life cycle steps of the packaging (i.e. REBIOFOAM and EPS-benchmark) were taken into account, whereas the production of washing machines was left out because it did not affect the comparison. Overall the LCA profile of the REBIOFOAM packaging has been determined with a good approximation. In particular a special attention was dedicated to the evaluation of the robustness of obtained LCA results. To this end several tools were adopted like inventory data checks, mass balance checks, Monte Carlo simulation and sensitivity analysis for the key parameters. Expanded packaging systems like those made of EPS are generally characterized by a short life becoming a waste to be handled very quickly. Due to cost-effectiveness issues like low quantities, low bulk density, difficulties in separating and identification of plastics by the end user, EPS packaging wastes generated at house hold level are generally characterized by a low recycling rate.

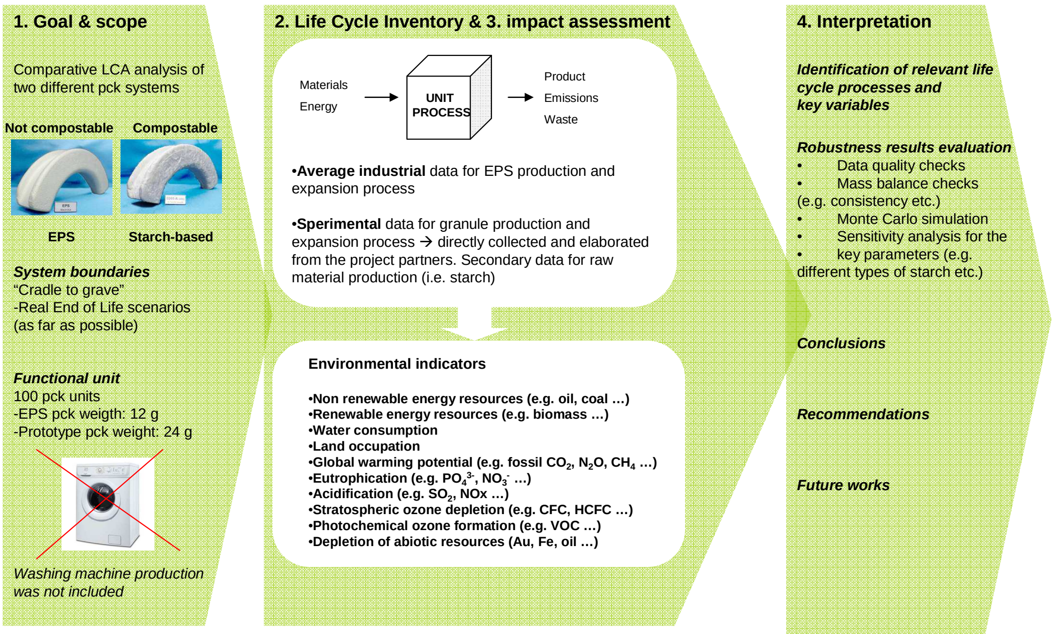

Figure 14 - Methodological overview and main WP8 activities

A biodegradable and compostable packaging system like the prototype developed within ReBioFoam project (i.e. porthole spacer) is potentially suitable for inclusion in the industrial composting process or home composting, or the waste water system opening up new routes for waste treatment. As the collection of the bio-waste fraction of Municipal Solid Waste (MSW) across the countries, where washing machines are sold, was estimated to be about 40%, a potential (biological) recycling rate for prototype packaging of 40%, without modifying waste collection schemes currently running would be expected. On the contrary, for a traditional (not compostable) expanded packaging system, the estimated recycling rate ranged from 0% up to 2.5%, on average 0.5%. According to such figures it could be argued that a compostable packaging system may increase diversion from landfill. A preliminary estimation suggested, de facto, that on average landfill would pass from about 52% (current scenario with EPS packaging system) to 37% (alternative scenario with a compostable packaging system), a reduction of 15%.

Beyond potential beneficial effects on waste management, the prototype packaging was assessed also from a life cycle perspective using LCA methodology performed largely following ISO 14044 standard. The analysis covered the most significant life cycle stages of the prototype like raw material acquisition, prototype packaging production and its disposal. Primary data reflecting the best trial outcomes for the prototype packaging were used and obtained LCA results were compared with those characterizing EPS packaging system, whose LCA was largely based using average industrial data representative of European production. From a LCA perspective, the prototype packaging showed a lower non renewable energy and abiotic resources consumption (-50% for both categories) along with a significant reduction in greenhouse gas emissions (-60%) compared to EPS packaging. This was mainly due to the use of a renewable feedstock. Also photochemical ozone production potential resulted significantly lower (-90%) thanks to the absence of the expanding agent (i.e. pentane) used instead in EPS expansion process. The robustness of these preliminary results was verified by performing a Monte Carlo simulation whose outcomes confirmed the reliability of LCA results. The results obtained by the project are drawing concrete perspectives for commercialization and other forms of exploitation: the potential for exploitation as emerging from the work developed within the project is in fact expected to generate strong interest in the industrial community. Therefore, it was also of primary importance that the partners agreed on an appropriate Business Model, describing in details the strategies to be adopted and the agreements on potential market for the new products, etc.

The major exploitable result coming from the ReBioFoam project is the integrated technology, including the ReBioFoam material and the plant for pellet expansion and production of packaging products.

Several future commercialization structures and Business Models are possible such as the establishment of a NewCo, involving some of the partners involved in the ReBioFoam project as well as other partners/investors interested in developing new products with the proposed technology. In this scenario, the NewCo may be mainly responsible for the commercialization of the integrated technology and may be also responsible for the engineering and commissioning of the plant.

In this scenario the NewCo will not deal with production, but only with commercialization and perhaps engineering of the integrated technology developed within ReBioFoam. It will thus be a service company which will deal with plant commissioning and implementation supported by specific components suppliers (i.e. Novamont will be the supplier of bio-based granules).

The proposed business model for the ReBioFoam integrated technology has a value driven structure, in which the added value of the product/service relies on the performances and sustainability of the final packaging product obtained with the proposed technology in line with the new upcoming norms and standards (i.e. green products) In this sense, the reference market is represented by the market of other green packaging solutions, as paperboard or other solutions.

WP9 IPR MANAGEMENT, EXPLOITATION, DISSEMINATION

Work Package 9 was notably focused on the definition of an exploitation strategy involving all players composing the value chain. A high focus was also given to dissemination activities in order to magnify the impact of the project on the wide spreading of the proposed environmental friendly packaging foam.

Novamont, as WP Leader, was in charge of preparing the “Plan for the Use and Dissemination of the Foreground”, which is one of the compulsory reports that participants in FP7 projects are required to deliver to the European Commission, summarizing the Consortium’s strategy and concrete actions to protect, disseminate and exploit the foreground generated by the project. With this respect, activities performed within WP9, reflect the structure of the “Plan for the Use and Dissemination of the Foreground”, which is divided into two sections: Section A “specifying the exploitable foreground and providing a plan for exploitation, including IPR management”, and Section B describing the dissemination measures.

SUMMARY OF THE MOST IMPORTANT RESULTS / ACHIEVEMENTS

The ReBioFoam project has generated interesting results. Here follows a list of the most important results:

- The materials formulation has been defined as well as the process parameters for **pellets** production; the pellets produced at semi industrial level have proved having good homogeneity, proper water content and morphology and defined chemical physical properties both at the pellets and at the foamed material level.
- A flexible and energy-efficient **microwave heating process** to produce 3D-shaped items has been defined and implemented toward the realization of a continuous process line at the semi industrial level. Particular focus was given to mould development as well as to microwave cavity design, which also included optimization of the inside field homogeneity.
- Key features of the **mould** which enhance product properties have been identified; smooth surface and hot surface led to the production of a prototype mould which provided good quality, low density products and to the development of a good understanding of doping mechanisms and mould design.
- **Microwave cavity** design, along with inside field homogeneity, were optimized by test productions of prototypes, expansion tests and the simulation of microwave fields into several designs of cavities. This led to the definition of the optimal and most energy-efficient microwave cavity solution and to the production of items with density of 40-50 kg/m^3.
- The possibility to reach the target density even at low pressure implied a significant advantage for the project particularly as regards the exploitation potential of the technology, while not implying any change to the original goal and objective of the project thanks to the obtainment of a more scalable and easy way to obtain the envisaged foam products at a semi-industrial scale.
- Two **demonstrators** were selected, defined and realized: a port hole spacer for washing machines and a corner for packaging application. The former was developed at lab as well as pilot scale; a density of 40-50 kg/m3 was reached for both. The port hole spacer as well as the corner properties were analysed. Results confirmed that their properties are comparable to those of EPS material, which was used as reference. Ambient performances are better for the most important impact categories. Moreover, the product is biodegradable and compostable in home and industrial conditions.
- A fully automated semi-industrial pilot line has been developed, which is able to produce foamed samples with density 40-45 kg/m^3.

Potential impact and the main dissemination activities and exploitation of results

Potential impact

The expected impact of the ReBioFoam project should be placed in a larger context. When the ReBioFoam project was started, a technical feasibility study, complemented by laboratory trials, had already demonstrated that starch could be used as basic raw material to produce a novel lightweight (density achieved so far of 40 kg/m^3) and cushioning foam that could be moulded to 3D shapes to be applied for transport packaging applications. The novel foam was intended to be an alternative to EPS, which can be moulded into virtually any shape or size and represents the most largely applied foam material in transport packaging.

Within the ReBioFoam project, building on this preliminary experience, an energy-efficient and environmentally-sustainable manufacturing process enabling the production of biodegradable foamed 3D-shaped packaging originating from tailor made expandable anisotropic skinned pellets made of slightly modified starch with controlled water content was developed and implemented at pilot semi-industrial scale.

In terms of pellets production, formulation and blending were optimized, the processes have been up-scaled during the course of the project and today the blend is extruded into controlled morphology pellets of small size, defined water content and a denser skin achieving the required tailor made specific chemical, physical and functional properties.

In terms of 3D foamed items production, a new microwave-assisted moulding process was developed and up-scaled during the course of the project, leading to the implementation of a new process concept. A fully automated semi-industrial pilot line has been developed based on this concept, which is able to produce foamed samples with density 40-45 kg/m^3. The ReBioFoam project has allowed to significantly increase the knowledge over the involved processes and serves as a platform for further developments. Furthermore, the possibility to reach the target density even at low pressure (instead of at high pressure as planned in the beginning) implied a significant advantage for the project particularly as regards the exploitation potential of the technology, while not implying any change to the original goal and objective of the project thanks to the obtainment of a more scalable and easy way to obtain the envisaged foam products at a semi-industrial scale. Finally, the fact that the microwave assisted foaming process has been now up-scaled and the feasibility of the process has been demonstrated will enhance the likelihood for this technique to be used in the production of biodegradable 3D-shaped foam applications.

The total production of EPS in Europe is 1,600,000 tons/year (Eumeps 2008). Of this, about 400,000 tons is used for packaging, which is the second largest application for EPS after construction materials. The production volume of EPS has been stable over the last years. While volumes of traditional packaging has decreased in Western Europe, there is a growing demand for shape-moulded construction details of EPS that combine excellent insulation and good mechanical properties at a low density. ReBioFoam foamed material is a good alternative for EPS with respect to shock protection. It has great potential to take a substantial share of the European EPS market. Property wise it will be possible to substitute at least 25% of EPS packaging, corresponding to about 100,000 tons/year of EPS. The availability of ReBioFoam resins need, however, to be improved in order to reach these levels. Preliminary studies and business model evaluation pointed out that the major exploitable result coming from the ReBioFoam project is the integrated technology, which includes the ReBioFoam material and the plant for pellets expansion and production of packaging products. An evaluation of the costs of the Rebiofoam demonstrator has been carried out taking into account the several hypotheses on a possible configuration of the pilot line defined within WP6 at a semi-industrial level.

Cost analysis contribution CAPEX/OPEX for the whole process (from the raw material to the demonstrator) has been evaluated as well as the financial analysis (NET, Payback, IRR) to define:

- if the hypothetical structure we analysed was feasible and sustainable;
- the target CAPEX/OPEX and the working area respect to the actual situation.

Taking into account the several hypotheses done because of the lack of a real industrial plant yet, the results are promising.

Main dissemination activities

The dissemination activities were aimed both nationally and internationally (specifically in Europe). The tools that were used for dissemination are (the list being not exhaustive):

- Publications
  - Articles in technical journals as well as in popular magazines
  - Publications on related portals and magazines, mailings, etc. dealing with environmental issues and, more in particular, related to the use of bio-based foams for transport packaging
- Conferences
- Workshops
- Seminars
- Press releases
- Showcases and exhibitions
- Internet
  - ReBioFoam Project Website
  - Specialised web portals
  - Forums
- Links to other projects
- Leaflets, brochures and posters
- Common graphic identity
- Promotional video

Furthermore as Coordinator, Novamont organized a final launch event to present the results of the 4-year ReBioFoam research and experimentation. The results were presented on the 30th January 2013 during an international conference that took place in Novara, in the Lecture Hall of the Faculty of Economics, at the presence of Project Technical Assistant and of representatives of the project and of the Italian Ministry of Education, University and Research. During the conference the promotional video of the project has been shown publicly for the first time.

Moreover, a demonstration event has been organized in the same day in Tortona, at Chemtex' premises, in order to raise the attention of the stakeholders of the relevant industrial sectors.

Exploitation of results

The main elements that constituted the new ReBioFoam concept are:

- Starch based pellets
- Mould
- MW oven

- Pilot line
- Foamed packaging items

The exploitation of the new concepts, and then of its elements, could be described with six stages with stop/go decision points in between, as illustrated below (Figure 15).

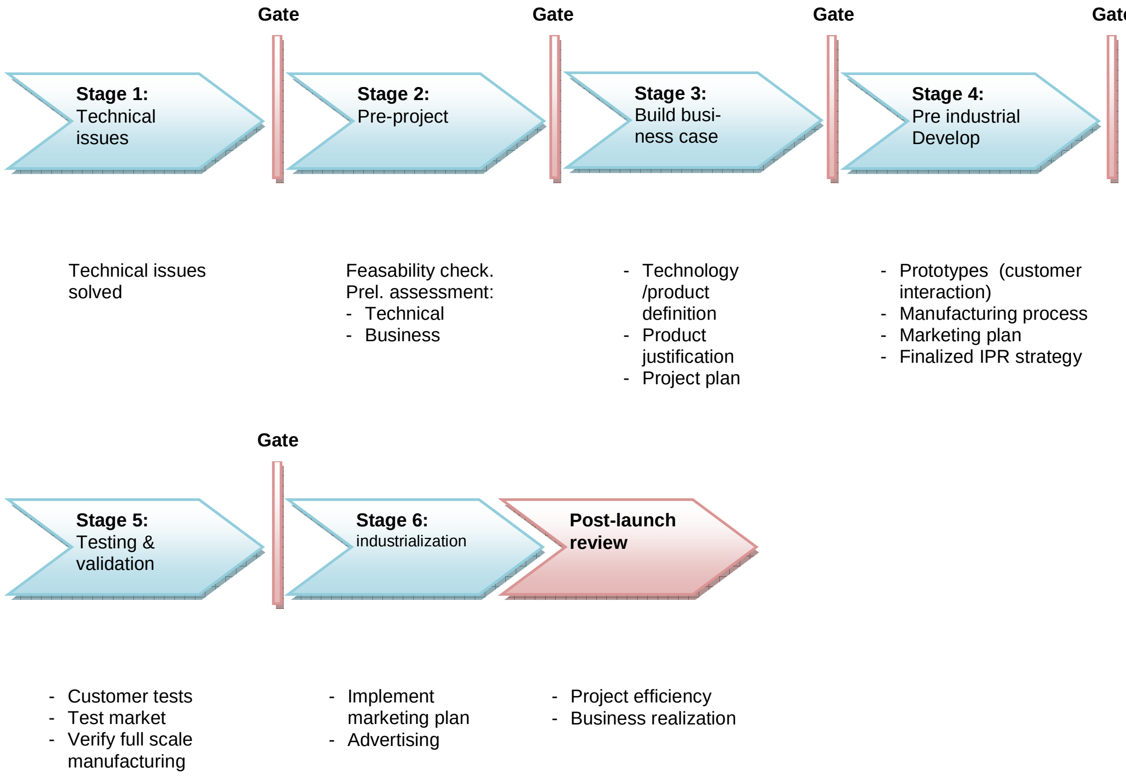

Figure 15 – ReBioFoam new concept exploitation

As during the project the level of achievements were different for the different elements, for each one a different maturity level was reached. As in particular:

1. **Starch based pellets**

Stage 4 - The pellets were produced at semi-industrial level setting and optimizing an equipment that is a scale down of an industrial one. The results of the tests confirmed the industrial feasibility up to a production capacity of 1000 kg/h; further tests are needed in order to set up an industrial line for pellets production.

2. **Mould**

Stage 4 - The moulds were produced using existing technologies. In case of an industrial line implementation, other materials may be investigated (e.g. injection or compression moldable materials). The developed moulds were validated in terms of functionality and design.

3. **MicroWave oven**

Stage 4 - The MW oven was designed for the pilot line, giving important information related to the power and time needed for the foaming of the pellets. The developed MW oven is defined for the production of pieces having dimension comparable (or lower) to the demonstrator (about 1 L). For different products a new design may be studied and in case of the set up of an industrial line, other technologies may be investigated.

4. Pilot line

Stage 4 - It is the core of the process that connects all the parts. It was demonstrated that the line is able to work autonomously with a minimum interaction of operators. The line was set up thanks to studies, information and feedback coming from all the project partners. The design of an industrial line will be probably different and will need to be studied in order to maximize the production capacity and minimize operative costs.

5. Product

Stage 4 - Properties of the foamed products were deeply analyzed. The results pointed out that the properties are comparable to those of the reference EPS. The ambient performances are better for the most important impact categories. The product is biodegradable and compostable in home and industrial conditions.

Address of the project public website, and relevant contact details

PROJECT PUBLIC WEBSITE AND CONTACT DETAILS

The ReBioFoam project has an open website available on www.rebiofoam.eu. On the website, information about the project vision, goals, consortium, newsletters and events are published. The coordinating organization was Novamont, and the coordinator was Roberto Lombi (strategic.projects@novamont.com; tel: +39 0321 699 611).

REBIOFOAM CONSORTIUM

The ReBioFoam project was executed by a consortium composed of 10 partners from 8 European countries. The involved organisations are listed below:

Industrial partners

- Novamont S.p.A, Italy
- C-Tech Innovation Ltd, UK
- FEN srl, Italy
- Chemtex SpA, Italy
- Recticel BV, The Netherlands
- Com-plas Packinging Ltd, Ireland
- Electrolux Poland - Spółka z Ograniczoną Odpowiedzialnością, Poland

Research institutes

- ITENE (Instituto Tecnologico del Embalaje, Transporte Y Logistica), Spain
- Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V, Germany

Universities

- CTU (České vysoké učení technické v Praze)