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CONTENTS

TABLES

FIGURES

1 EXECUTIVE SUMMARY.

About 5% of global carbon emissions originate from the manufacturing of cement. According to IEA, cement production generates an average world carbon emission of 0.81 kg CO_2 per kg cement produced. Cement related emissions are expected to increase by 260% throughout the 1990-2050 period. As consequence, the global production of cement in 2030 is projected to grow to a level roughly 5 times higher than its level in 1990, with close to 5 billion tones worldwide. Emissions of the global cement sector alone are very likely to surpass the total amount of CO_2 emissions of the EU before 2030. As well, Industrial waste is now global concern, causing environmental and economic harm. Industries are rapidly trying to find a solution, searching for optimal ways to manage waste and to change the most common practices as landfill or incineration. Industrial waste is very heavy burden for the environment, where a significant proportion of this industrial waste is attributable to construction and demolition waste. To mitigate these threats ECO-CEMENT will allow recovering valuable resources from industry, capturing CO_2 and transforming both products into ecological cement that can be used in construction or novel environmental applications. Based on the nature's way of creating natural formations through bacterial contribution to carbonate precipitation, the main objective of ECO-CEMENT was to develop a novel bio-mimetic technology for enzyme-based microbial carbonate precipitation through the revalorization of industrial waste as raw materials, in order to produce eco-efficient environmental cement. The Bio-mimetic Technology will convert industrial waste, mainly cement waste and others by-products, into high strength, ecological cement using microbial carbonate precipitation via urea hydrolysis. Internal studies suggest that the combined use of industrial waste and the implementation of Eco-Cement technology can reduce GHGE from cement manufacturing by up to 11 % and 20 % reduction of construction waste.

1.1 Technical Achievement.

Calcium binder.

We have identified that **CKD** is the only source of lime from the cement industry wastes. The right Cement Kiln Dust is that one coming from the precalciner bypass filter.

Calcium lactate could be a possible alternative source of Calcium idroxyde (in basic environment) and it is very soluble (7.9 g/100 mL at 30 °C). It could be obtained from milk and cheese waste and in the same time to supply the bacteria with organic nutrient.

Influence of temperature and pH.

Due to the CKD components we cannot lowered, in a suitable way the pH (>12), and on the basis of the mode of action we cannot control the Temperature (40-50 °C) during the blending. However the bacterial strain tested (*Sporosarcinia pausterii*) has demonstrated its ability to survive in such extreme conditions and operates the urea hydrolysis.

Influence of urea and urea substitute.

It was observed that the optimum of urea concentration for the maximum urease activity is about 1M, but 0.33M was considered satisfactory for the cementation purposes. The urea used, for the moment, is coming by commercial fertilizer sector. It is clear that this is not an industrial by-product but it is cheap and it will be substituted by the urea produced by biomass system.

Hydraulic component.

GGBS and RHA were tested and the more suitable was RHA with high content of amorphous silica.

Alternative nutrient source for the bacterial growth.

Among the several alternatives the most suitable were products coming from Dairy Industry Wastes (Whey and Permeado).

Microbial inoculum production for cementation purposes.

Dry powder composed by 100 g of the **PAV** and 100 ml of Bacterial biomass (exponential phase) in H_2O with dissolved FU (2%).

Process scale-up.

The bacterial biomass has been produced, in successive batches, in the 5 litres bioreactor and dry stored in the PAV for demo use and future applications.

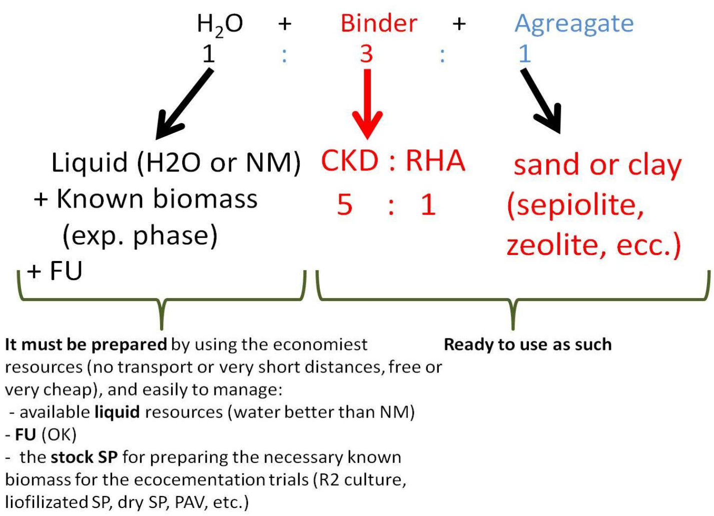


Figure 1: ECO-CEMENT Process scale-up

1.2 Final Products.

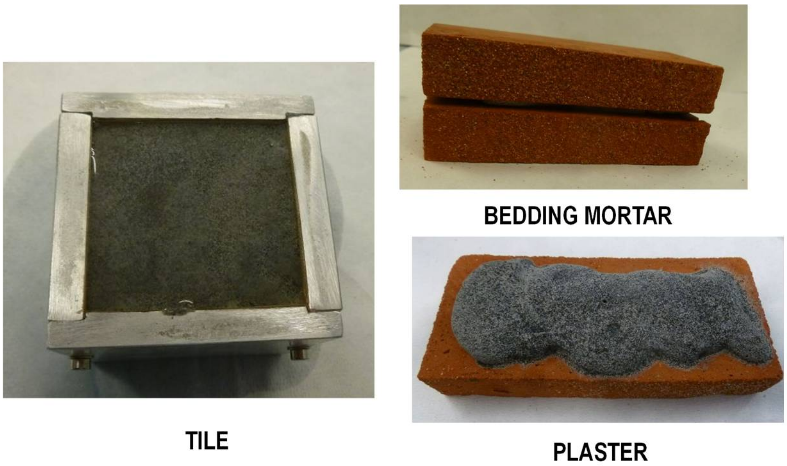


Figure 2: ECO-CEMENT final products.

1.3 Improvements.

- Substitute the CKD with biomass ashes. These coming from wooden matter are rich in CaO and free calcium ions and could be used instead of the CKD avoiding the presence of unwanted components. This aspect needs some experiments in order to verify the best ashes and their composition and concentration.

- Insert in the paste some fibers for increasing the strength. These could be derived from wool residues or from basalt.

- Realize the tiles using vibro-compress system.

1.4 Future risks.

- Availability of the components for the market.

- Effective hardness of tiles and their durability.

- Properties of mortar and plaster.

- SMEs for local production and marketing.

- Selection of possible end-users.

2 SUMMARY DESCRIPTION OF THE PROJECT CONTEXT AND THE MAIN OBJECTIVES.

The ECO-CEMENT project is focused on one of the most promising processes for producing a Portland cement substitute: the "Microbial induced calcium carbonate precipitation (MICP)" by the use of ureolytic bacteria. These bacteria are widely available in the soil and natural environment, can be easily controlled and have the ability to produce cementation at a comparatively much faster rate than current alternatives.

The mechanism of reaction involves ureolytic bacteria that hydrolyse urea to produce carbonate ions and in the presence of free calcium ions precipitate calcium carbonate. Urea is needed as a primary reagent. If the saturation levels of the calcium carbonate produced are sufficiently high, it will precipitate forming bonds and consolidating its surroundings in the MICP process. As these processes use naturally existing components for the carbonate precipitation process, the environmental impacts of this material will not be as strong as Portland cement.

This research project was structured in 4 different Work Packages (WP), which are complemented with two additional packages related to the marketing and dissemination strategy:

- WP2. The aim of WP2 is to investigate the use of cement industry wastes, specifically solid alkaline industrial wastes, as raw materials for the production of Eco-Cement.
- WP3 will investigate the biomimetic process for the production of Eco-Cement with the following objectives:
  - Select the most suitable microbial source for enzyme production
  - Determine the favorable growth conditions.
  - Develop an economical, industrial medium for large-scale production of microbial source
- WP4 will test the Eco-Cement technology in a pilot-scale trial with the aim:
  - Evaluate the performance of enzyme under cementation conditions.
  - Determine the strength development during the cementation reaction.
  - Test the Eco-Cement product in an industrial application.
- WP5 to evaluate the potential for energy savings, waste revalorization and reduction of emissions:
  - Establish a LCA methodology and adequate environmental indicators.
  - Assess the global environmental impact of Eco-Cement compared to three cement technologies (Portland, Novacem and Calera).
  - Show the benefits of Eco-Cement through the analysis of overall environmental efficiency.

The medium ingredients in biotechnology processes are a major cost factor, ranging between 10 to 60% of the total operating costs. The medium cost increases proportionally with the size of the scale up. Because of this, it is important to give due consideration to optimization of the medium prior to scale up.

Hence, for the large scale production of ECO-CEMENT inexpensive raw sources are needed. Reusing industrial by-products as a source of calcium, urea and bacteria´s nutrients contributes not only to reduce the process costs but to minimise the environmental impacts associated to the disposal of such wastes.

Thus, t***he objective of WP2 was to investigate the use of industrial by-products and its potential to be reused to produce Eco-Cement.*** These sources are much cheaper than the laboratory industrial medium but they would rather require some pre-processing which would add a small additional cost in order to reduce the presence of contaminants and non desired bacteria.

Complementary, ***WP3 identified the urease production bacteria, how the urease reaction is governed, studied and simulated the biocementation process*** The WP3 worked on analytical methods to determine the microbial activity and its performance. Based on these analytics, the microbial process was optimized and upscaled for a suitable and cost-effective calcite production. Due to the dependency on the industry waste selected, WP3 is closely linked with WP2 by the requirements of industrial waste.

In ***WP4, ECO-CEMENT was upscaled and demonstrated in a pilot site***. The performance of the pilot structure was monitored to check the real benefits brought by the project. ***WP5*** was established a ***Life Cycle Assessment (LCA)*** methodology particularized to ECO-CEMENT process. The aim was to assess the global environmental impact of Eco-Cement compared to three cement technologies (Portland, Novacem and Calera). By these means, we were able to ***measure the project overall environmental efficiency***.

WP6 defined the business plan, IPR and marketing strategy in order to commercialize the product. Finally, all the knowledge generated in the project were disseminated following the ***Awareness and Dissemination Plan defined in WP7.***

3 DESCRIPTION OF THE MAIN S & T RESULTS / FOREGROUNDS.

3.1 WP2.- Defining the system. approach for Cement Industry Wastes and its use as raw materials for ECO-CEMENT.

The medium ingredients in biotechnology processes are a major cost factor, ranging between 10 to 60% of the total operating costs. The medium cost increases proportionally with the size of the scale up. Because of this, it is important to give due consideration to optimization of the medium prior to scale up. Given that biocementation process does not require ease of removal of medium components or use of a defined medium, we are able to look at a range of more economical components to replace the existing expensive analytical grade chemicals.

Therefore, the objective of Work Package2 was to investigate the reuse of industrial by-products for the large scale production of ECO-CEMENT. These alternative sources are much cheaper than the laboratory industrial medium. Reusing industrial by-products as a source of calcium, urea and nutrients has dual benefits as it contributes, not only to reduce the process costs, but to minimise the environmental impacts associated to the disposal of such wastes.

Another purpose of Work Package 2 was to identify the Key Performance Indicators (KPIs) that will be used in the future Work Packages to verify the efficiency of ECO-CEMENT applied technology. These KPIs will help in comparing the ECO-CEMENT performance versus Ordinary Portland Cement and quantifying the real energy and emissions savings derived from the project.

The most significant results and main conclusions have been:

- Investigate the use of Solid Alkaline Cement Industry Waste, as a calcium source to produce ECO-CEMENT: Sources of solid waste in cement manufacturing include clinker production waste, mainly composed of spoil rocks, which are removed from the raw materials during the raw meal preparation. Another waste stream involves the kiln dust removed from the bypass flow and the stack. Limited waste is generated from plant maintenance (e.g. used oil and scrap metal). Other waste materials may include alkali or chloride / fluoride containing dust build up from the kiln.

  We have identified that CKD is the only source of calcium from the cement industry wastes. Cement kiln dust is the dust which passes out of the top of the preheater with the exhaust gases, or more typically out of the back of a long dry kiln.

  Overall, the data examined indicated that there exists no “average” CKD, and that each CKD source should be considered as having its own unique properties. Therefore, multiple samples from different kilns were needed to produce statistically significant results because of the inherent differences between cement plants and within the process of each cement plant, from variations in raw materials, fuels, equipment design, kiln operations, etc. The variability in the composition of CKD, and in particular the large range in variation in free lime content, highlight the importance of fully characterizing a particular CKD sample before recommending it for reuse as part of the ECO-CEMENT process.

Preliminary experiments were carried out with samples obtained from Vassiliko Cement plant in Cyprus. The CNR-ICVBC analyzed, characterized and tested these samples. This results have demonstrated, that Vassiliko samples were not suitable as the calcium found was mainly calcite without CaO and $Ca(OH)_2$. The sample was found not suitable after enhancing its calcium content by some of the following methods:

- High speed grinding to activate the Calcite 'present in the sample.
- Adding activated clay minerals with pozzolanic properties.
- Adding Nanocomponents of silicates after their mechanical activation.
- Adding rice husk ash and/or egg shells.
- Adding some natural stones such as Alberese (marly limestone) needs to be heated at 800°C.

We have identified that the lack of free lime can be attributed to the fact that the Vassiliko sample could have been stockpiled. Once CKD is exposed to moisture, the alkali sulfates are likely to go into solution. Free lime and some cementitious phases, if present, may undergo hydration or carbonation. Thus stockpiled CKD may contain some prehydrated or carbonated lime and hydrated cementitious phase which all may contribute to high Loss of Ignition (LOI) and absence of free lime. Therefore, we needed to work with fresh CKD samples.

In parallel, more samples of CKD were collected; 2 samples from Holcim (Spain) and another 2 from Heidelberg Cement (Germany). All the experiments have been repeated with these additional CKDs. In particular, the CKD Bypur (Heidelberg sample) showed the highest CaO content and promising properties to act as the binder to form ECO-CEMENT. This gave us an indication on the exact point where the samples should be collected (alkali by-pass). We have concluded that samples extracted from the alkali by-pass would have a content of free lime enough to meet ECO-CEMENT requirements. This will help in avoiding the dependence of the use of CKD as function of the waste source.

The research will continue inside WP3. More samples of CKD, collected from the alkali by-pass, are going to be chemically analysed in order to confirm the assumption that CKD from the alkali by-pass is always suitable for our process.

In summary, the Task 2.1 has concluded that CKD can be considered as an alternative calcium source as very promising results were obtained from the Bypur sample (Heidelberg cement). The composition of CKD is highly variable with the manufacturing process and this highlights the importance of fully characterizing each particular CKD sample before incorporating it to the ECO-CEMENT process. Samples collected from the alkali by-pass seem to have enough content of free lime to meet ECO-CEMENT requirements. This will limit the dependence of CKD to the waste source. The research will continue in order to prove this assumption. For that, more samples of CKD will be collected and chemically analysed.

- <u>To identify inexpensive sources of urea and nutrients that could be supplemented to the ureolytic bacteria to maintain high urease production rates:</u>
  - **Urea**: Traditional sources of urea are excretory products; faeces and urine. The quantity of manure produced varies considerably among species because of differences in animal

diets and metabolism, and within species due primarily to differences in management. Also the humidity, age and environmental factors influence its production. All these facts make the supply very irregular and unreliable. On top, manure contains pathogens, viruses, etc. that need to be eliminated before its application to ECO-CEMENT. This adds an extra cost that, in certain cases, can be unaffordable if we want to lessen the process expenses.

Another source of urea is fertilizers. Fertilizers offer a good urea source without the need of being pre-treated. It is clear that they are not industrial by-products, but they are cheap (around 6€/kg), even when compared to urea rich by-products that require expensive pre-treatments. *For this reason, fertilizer urea will be the primary urea source used in the laboratory.* However, it derives from fossil fuel hydrocarbons and, hence, it produces a high environmental impact.

To avoid this, we are investigating the *possibility to incorporate bio-urea to our process; urea from biomass, with a negative and low environmental impact.* Concluding results will be presented once the research in WP3 has finished.

- **Nutrients**: A reduction in the medium costs without loss of urease activity is possible by the substitution of laboratory grade yeast extract by each of the following industrial by-products: Corn Steep Liquor (CSL); Torula Yeast; Brewery waste yeast (BWY); Sludge Biomass from WWTP, and Lactose Mother Liquor (LML):
  - **Torula yeast (Candida utilis)**. There was found only one reference in the literature related to microbial calcite precipitation by the use of Torula yeast, but these results were not completely satisfactory. Further research is needed in order to assess the urease activity produced by the use of Torula yeast. However, as the project has time limit constraints, Torula yeast was not recommended as medium for the bacterial growth.
  - **Sludge biomass from WWTP**. This by-product has a high content in toxic heavy metals and other potential carcinogenic pollutants, so pretreatment methods are needed to lower the metal content in the sludge. Pretreatment methods add an extra cost that has to be avoided and sludge biomass has been discarded as a cost-effective alternative.
  - **Corn Steep Liquor (CSL).** It has been demonstrated that the corn steep liquor is a suitable nutrient source for the growing bacteria as it produces good levels of urease activity. However, it is not widely available in Europe, so other industrial by-products had to be considered that showed better availability and similar enzymatic results.
  - **Brewery waste yeast (BWY).** Several attempts have been made aiming to reuse the surplus brewery yeast in biotechnological processes as a source of nutrients. However, brewery waste yeast is largely comprised of whole cells that result in them being inaccessible to the growing microorganisms, but this could be improved in further investigation. There are other industrial by-products that suit better the project

requirements. Then, brewery waste yeast is not recommended as medium for the bacterial growth.

- **Dairy Industry Wastes (DIW)**. DIW (Lactose Mother Liquor; Buttermilk and/or whey) are good sources of nutrients that can support the growth of *Sporosarcina Pasteurii,* and maintain a level of urease activity sufficient for cementation. As a plus, the availability of this waste is guaranteed by a regular supply. This is the waste source that will be used to upscale the production of ECO-CEMENT.

*In conclusion, from the cases analysed, DIW is the better nutrient source for the growth of the bacteria and for the calcite precipitation. Using DIW instead of the standard media not only reduces the process cost but also prevents the environmental pollution. Samples of this material (lactose mother liquor, buttermilk and whey) have been collected and analysed. The research in WP3 will indicate which of the dairy waste products is the optimum for ECO-*CEMENT.

- To set out the environmental requirements of the industrial waste analyzed in previous tasks, based on the information available and still being researched and tested by other partners.

  The report outlines in two diagrams the Material Flow Analysis of the inputs and flows of materials, energy and water in the proposed Eco-Cement process. This forms the starting point diagram for the LCA analysis. It also discusses the barriers to technical and scientific deployment of such an Eco-Cement by considering the environmental, social and economic issues.

  As the research has not concluded the report focuses on the general 'systems thinking approach' to developing a robust Eco-Cement process with no environmental impact. This challenging objective will likely require a very wide boundary to our Life Cycle Assessment (LCA) analysis in order to include sufficient natural processes to mitigate any negative environmental impacts of the proposed Eco-Cement process. The report will require more work to complete when the research on WP3 is completed.

  The most significant result and main conclusion of this Report is the need to achieve a 'closed loop' in the ECO-CEMENT production process in order to achieve a truly "Eco" cement. This requires an applied systems approach which will need to be tested in a rigorous LCA analysis in WP5.

- To review the Key Performance Indicators (KPIs) of cement industry and presented the KPIs of the bioenzymatic system.

  The ECO-CEMENT project specific indicators are given below:

Table 1. ECO-CEMENT project specific indicators

№	KPI	METRIC	OPC
Environmental KPIs			
1	Tonne CO_2 / Tonne Cement	Tonne/Tonne	0.67 t/t
2	Tonne CO_2 / Tonne Processed Material	Tonne/Tonne	0.85 t/t
3	Heavy Metals	micrograms	n/a*
4	Organic Compounds	micrograms	n/a*
5	Waste Water	Litres/Tonne	702 l / t
6	Waste Used as Process Fuel	Percent	12.3%
7	Waste Used as Additives	Percent	0-95%
Energy KPIs			
8	Total kWh / Tonne Cement	KWh/Tonne	859 kWh / t
9	KWh (Electric) / Tonne Cement	KWh/Tonne	108 kWh / t
10	MJ / Tonne Processed Material	MJ/Tonne	3580 MJ / t
Process KPIs			
11	g $CaCO_3$ / l	g/l	n/a*
12	g $CaCO_3$ / kg Final Product	g/kg	n/a*
13	Biomass / Time Production	kg/hour	n/a*
14	Urea/(Time*Biomass)	kg/(hour*kg)	n/a*
15	Ca^{2+}/Biomass	kg/kg	n/a*
16	Additives/Cement	kg/kg	n/a*
17	Cost Saving for the Recommended Medium	€/€	n/a*
Performance KPIs			
18	Compressive Strength	MPa	20-35 MPa
19	Tensile Strength	MPa	2-5 MPa
20	Flexural Strength	MPa	3.9-5.1 MPa
21	Time to Cure to OPC Strength	Days	28 Days
22	Depth of Cementation	mm	n/a*
Economic KPIs			
23	Cost	€/Tonne	€90 / t
24	Tonnes Cement / Year	Tonne/Year	890,000 t / a
25	Investment Cost Per Tonne/Annum	€/Tonne/Year	€170 / t / a

* No corresponding value for OPC

KPIs 13-17 are explained as follows:

- 13. Biomass/time production [Kg/hour] as a function of organic supply, pH and T°C, For evaluate the cost of producing the *ureolityc bacterial biomass*
- 14. Urea/(time*biomass) [Kg(/hour *Kg)] the consumption of urea as indicator for the production of ammonium and carbon hydroxide.

For evaluating the efficiency of the bioenzymatic production of *carbonat*

- 15. Ca^{++} (CKD?)/biomass [Kg/Kg].
- This indicates the demand of free calcium (as ions in the CKD) (as a function of the biomass) for produce new *Calcite.*
- 16. Additives/Eco-cement [Kg/Kg].
- Possible additives. The additives could be necessary to improve the strength and the compactness of the final product
    - i. CO_2.
    - ii. LKD or activated clays.
    - iii. Nanocomponents of silicates.
    - iv. Rice husk ash and /or egg shells.
- **17. Cost saving for the Recommended medium** [€ (substitute)/€ (standard medium)]**.** Ratio of saved costs by using "low cost nutrients" for urease activity with respect to "high performance nutrients". *Substitutes:*
    - o Lactose Mother Liquor (proteins source)
    - o Dairy industry waste and milk whey (calcium source)
    - o Rice husk ash and /or egg shells (calcium source)
    - o Fertilize raw material (urea source)

The KPIs presented within this document are used across a range of work packages in the Eco-Cement project. Environmental KPIs are what will be determined and assessed in the LCA that will be performed in WP5. Energy KPIs will be also be determined and assessed in the LCA performed in WP5, but they will also be disseminated in WP6 and WP7 as selling points of the Eco-Cement process, along with the performance KPIs. Process KPIs, calculated in WP3 and WP4, will be used to ensure the Eco-Cement process is at its most effective.

3.2 WP3.- Requirements analysis of microbial process for a suitable and cost-effective Eco-Cement production.

The aim of the WP3 "**Requirements analysis of microbial process for a suitable and cost-effective ECO-CEMENT production**" was to determine urease producing bacteria, how the urease reaction is governed and to study and simulate the biocementation process. It was divided in five tasks.

The objective of the first **Task 3.1** was to investigate the suitable source of bacterial urease and various environmental and physiological conditions for maximum urease activity. The bacterial strain had to meet the following requirements: high urease production capacity, ability to produce urease in the presence of ammonium, high stability, consistent production and no further down-stream processing prior to biocementation use.
We compared the urease production capacity of several microorganisms to be used in the biocementation process. The bacterial strains *Sporosarcina pasteurii*, *Bacillus subtilis* and *Bacillus megaterium* were classified as theoretically suitable for ECO-CEMENT. These three selected bacterial strains were investigated in regard to their urease activity, calcite precipitation rate and their resistance against cement industry waste (e.g. cement kiln dust - CKD). Within these measurements, *S. pasteurii* showed the best results in comparison with *B. subtilis and B. megaterium*. The conductivity measurements revealed that *S. pasteurii* had the highest urease activity and is therefore the most suitable microbial source for enzyme production in comparison with *B. subtilis and B. megaterium*.

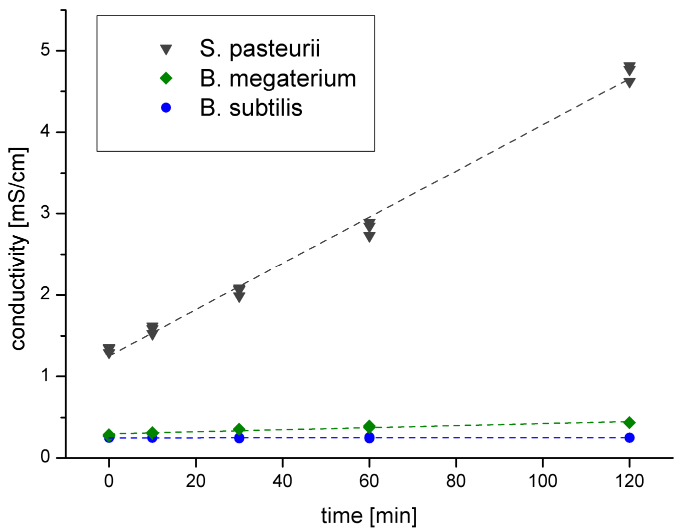


Figure 3: Conductivity measurements of B.subtilis, B.megaterium and S.pasteurii, over time; the linear fit (dashed lines) for the measurements gave an increase of 3,4*10-6 (mS/cm)/min for B. subtilis, 0,001 (mS/cm)/min for B. megaterium and 0,028 mL (mS/cm)/min for S. pasteurii.

The second **Task 3.2** dealt with the evaluation of the main parameters responsible for high specific enzyme activity. This was validated in classical biological experiments also by using the Bioreactor from CNR-ICVBC by which several parameters could be followed during the bacterial growth. The chosen ureolytic bacteria *S. pasteurii* should maintain a high specific enzyme activity in order to be used for the cementation process.

Therefore, the influence of some parameters (temperature, urea, pH, viability test in the presence of CKD, calcium concentration, bacterial density) on the vitality and enzyme activity of this bacterium was investigated. The most favourable incubation temperature for the laboratory protocols was established to be at 30°C**,** while for further ecocement production, a satisfactory efficiency of the bacterial activity can be obtained when the temperatures are higher than 23°C. It was observed that the optimum of urea concentration for the maximum urease activity is about 1M, but 0.33 M was considered satisfactory for the cementation purposes. In the extreme conditions of the alkalinity of the ECO-CEMENT process (pH higher than 10), the *S. pasteurii* cells were able to survive and to partially express their ureolityc activity (only about 36 % with respect to the bacterial cells incubated at pH 7). Further, calcite precipitation efficiencies of nearly 100% were observed, when the maximum free Ca^{2+} concentration was about 3-4 mg/mL.

Concerning the ECO-CEMENT cementation process, the resistance against the cement industy waste was crucial. The more important was the observation, that *S. pasteurii* was the only one of the tested bacterial strains that started to grow in the presence of CKD.

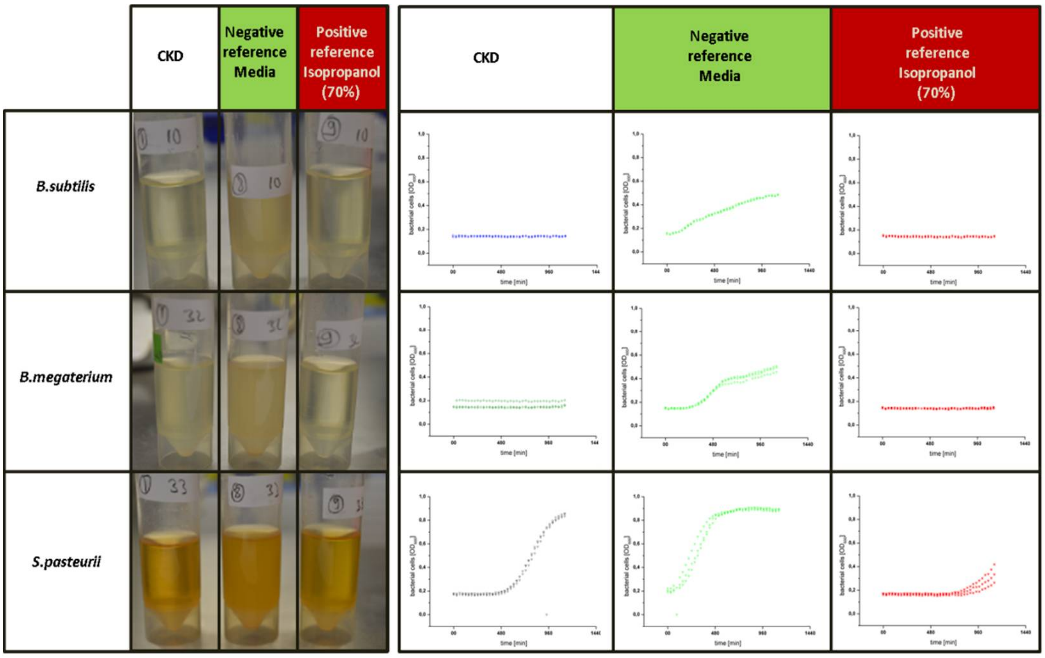


Figure 4: Viability test measured after incubation of B. subtilis, B. megaterium and S. pasteurii in the presence of CKD for 3 hours; inoculation of an aliquot in fresh medium after 18 h/ 30°C (left), growth curve of an aliquot in fresh medium 18 h/ 30°C (right).

The economization and optimization of the cultivation medium for the bacteria prior to scale up was the focus of **Task 3.3**. In terms of the economisation of the ECO-CEMENT process, several nutrient substitutes were investigated. The whey, present in the wastewater used for cleaning production systems of dairy industry (Mukki) was efficiently used as alternative nutrient source showing the most potential with regard to costs and ecological impact. Beyond the nutrient substitutes, fertilizer urea and poultry manure as pure grade urea substitutes were tested. It was proved that a less expensive fertilizer urea did not affect the bacterial growth neither the urease activity. Additionally, a way to provide the bacteria to the end users, using PAV type poultry manure, was tested. It turned out, that PAV is a suitable substrate for the dry maintenance of the *S. pasteurii* biomass in a living metabolic state, so that they are easy to reactivate by the end users. For verification, a dry microbial inoculum for onsite cementation purposes was checked and proposed as handy and easy source of the bacteria biomass for the ECO-CEMENT process. In fact, the PAV poultry manure was demonstrated a suitable substrate for the dry storage and viable maintaining of the *S. pasteurii*. This allows an easy transport and a quick revitalization of the bacterial cells and their enzymatic potential used for the ECO-CEMENT cementation process.

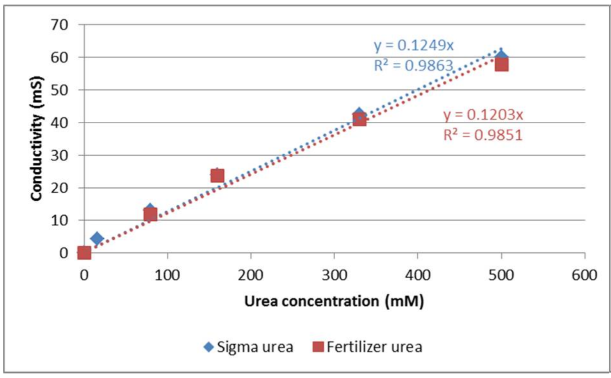


Figure 5: Hydrolysis of different urea concentrations (pure grade urea and fertilizer urea) by the pure urease.

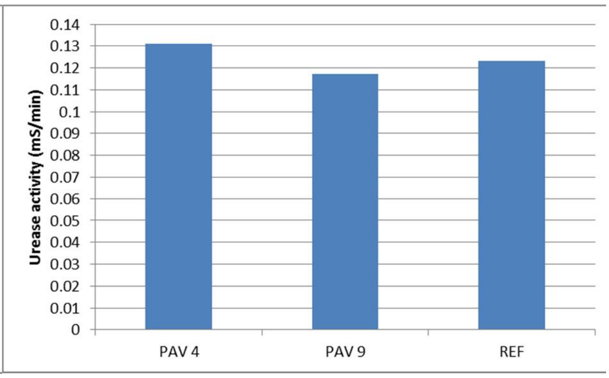


Figure 6: The urease activity of S. Pasteurii determined in revitalized microbial inoculum (PAV + water-urea solution (20 g/L) after 4 and 9 weeks of dry storage

Task 3.4 aimed to evaluate the performance of the enzyme under cementation conditions. Particularly, this Task was about the microbial calcite precipitation in the presence of industrial waste to give a final product that can be used as ECO-CEMENT. The investigations focused on the impact of the enzyme performance under cementation conditions and where the working boundaries of the process lie.

For evaluation of the performance, a trial standard and also testing methods were defined. Therefore, GGBS from DWEcoCo, obtained from EcocemLtd in Dublin, was used for the preliminary ECO-CEMENT production as a standard for a binder. This preliminary approach was continued by a systematically proof of potential substitutes for GGBS and other components within the process steps that were identified as critical in terms of the environmental or cost aspects. In WP2, industry wastes were defined as raw material for the Eco-Cement process. Based on this selection the Eco-Cement process was established and the components (Liquid/Biomass, Aggregate and Binder) were classified. The Liquid was defined as Biomass. At a later stage the pre-processing of cultivation was evaluated as inconvenient and it was intended to decouple the Biomass production from the grain-consolidation process itself.

As aggregate quartz sand, firstly sieved playground sand from the construction market were chosen. The binder was distinguished in cement industry waste Cement Kiln Dust (CKD) and Pozzolanic additive; first GGBS and later rice husk ash (RHA).

The run of trials was started in July 2013 during the laboratory action in Florence. Based on the first two trials, the consortium discussed the next trials during the mid-term meeting in Brussels and agreed in a trial planning. The first ECO-CEMENT samples made with Bypur (CKD from Heidelberg Cement, Germany) were prepared according to the grain consolidation protocol from CNR-ICVBC. Shore A measurements were taken three months after preparation of the samples and revealed that the bacteria *S.pasteurii* had a positive impact on the hardness of the cement sample. The Shore A of the reference made with only nutrient medium (without bacteria) gave 54± 4 Shore A and the ECO-CEMENT (with bacteria) gave 64± 2 Shore A.

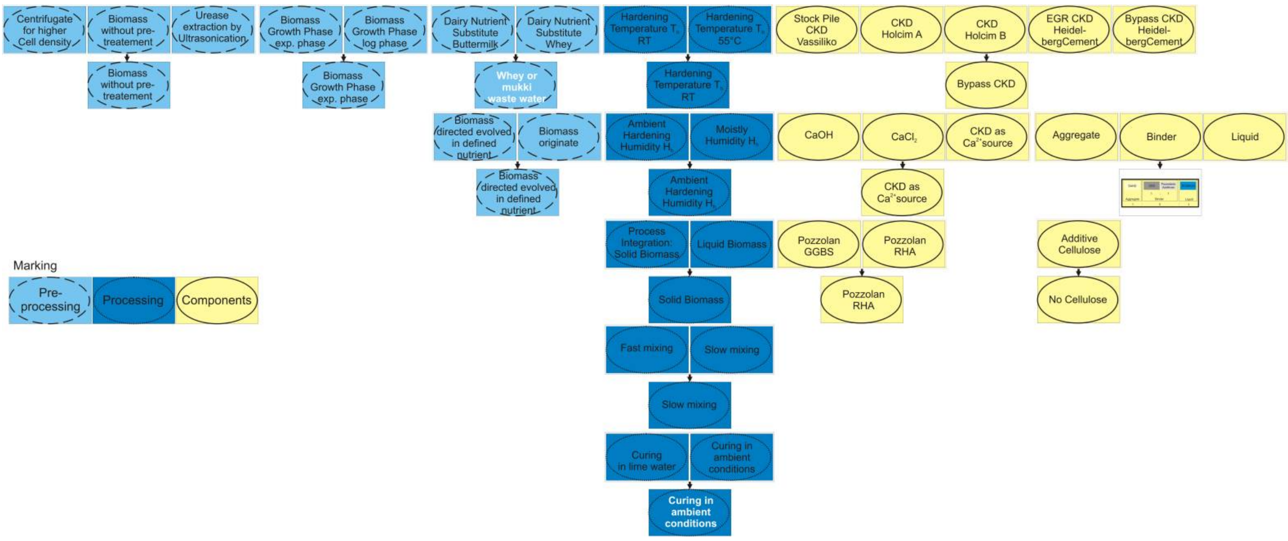


Figure 7: Trial Tree plan overview

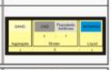
Trial	Parameter	Pre-processing	Processing	Components
Pretrials	Tested	Biomass (e.g. Cell density)		CKD samples of european cement plants
	Fixed	Cell density of OD^{600} 0,5 to 2; **no centrifugate**		**Bypass CKD**
1st	Tested 28 d hardening	Biomass Growth Phase (Exp vs. Log)		Composition (e.g. Ca^{2+}source)
	Fixed	Biomass in **Exponantial** Growth Phase		
2nd	Tested 28 d hardening		Hardening Temperature T_h (RT vs. 55°C)	Additives: Cellulose & Pozzolan (GGBS vs. RHA)
	Fixed		RT	**no Cellulose**
3rd	Tested 10 d hardening	Nutrient Substitute (Buttermilk vs. Whey)	Hardening Humidity H_h (ambient vs. moistly)	
	Fixed	Dairy waste	Moisture chamber	
4th	Tested 28 d hardening	Biomass directed evolved in defined nutrient	Process Integration (Use of solid Biomass)	
	Fixed	In dairy industry waste (mukki waste water or whey)	PAV	
5th	Tested 10 d hardening		Curing in ambient conditions vs. curing in lime water	
	Fixed		Ambient conditions	
6th	Tested 7 d hardening	Preconditioning of CKD	PAV	Different RHA qualities
	Fixed	No pretreatment of CKD		Indian RHA
7th	Tested 7 d hardening		Different Applications	
	Fixed		Tiles, Plaster, Bedding mortar	
8th	Tested 7 d hardening		PAV sieved or not	
	Fixed		Sieved PAV	

Figure 8: Detailed Trial Plan divided into the performed trials and their main results.

Further, test bricks were prepared using a blender at CNR-ICVBC or a laboratory scale cement mixing device at IFAM. Some of the bricks were tested with the drilling machine at CNR-ICVBC.The results indicate a hardening gradient within the bricks. Several conditions were varied, e.g. the state of bacterial growth, the composition of the nutrients and the ratio of the different components.

RESULTS OF THE TRIAL TEST CAMPAING:

N°1: Biomass type R2; suitable volume in exponential growth phase (OD 600 = 1-2).
Positive low reference medium: CASO (containing 8 g/l of proteins) supplemented with 0.33 M of FU (fertilized urea).
Calcium source: Bypass CKD from HeidelbergCement Plant.
Ratio- 1 :Aggregate (sepiolite) 3 : Binder (CKD + Pozzolanic component) 1 : Liquid (Nutrient medium with biomass).

N°2: Pozzolanic component: RHA was fixed.
Curing temperature - RT - Room temperature (20-23°C)
Additive - no Cellulose recommended

N°3: Nutrient Substitute – Whey.
Curing Mode -Not Wet (also considering the test according to ASTM made in Jan2014)

N°4: Biomass Source: PAV (up to now just the results of the Drilling Test are available)
Mixing Procedure: slow in order to avoid bubbles
RHA Quality: EDX indicates significant differences between Indian and Italian Quality (the CO2 impact of Indian RHA is critical)

N°5: Curing condition under lime water: no hardening in lime water (specimens collapsed).

N°6: Preprocessing of CKD by hydrating it: not necessary.Controlling the influence of different RHA types (Indian, Spain, Italy).

N°7:Evaluation of different products: Tile's, Bedding mortar and Plaster.

N°8: Preprocessing of PAV by seaving to separate the solid part by the liquid ones containing the bacteria and carbonate: better to sieve.

N°9: proportionally variation of each component (Neapolis).

The cementation process is dependent on parameters like the cement recipe and the temperature during the preparation, which raises critical values with respect to the bacteria. The composition of the several CKD samples were analysed and revealed significant differences in the CaO content, which is essential for the binding properties in the Eco-Cement process. Further parameters like the suitability of possible ECO-CEMENT component substitutes as for GGBS (chosen as a binder standard and pozzolanic additive) and sepiolite (chosen as aggregate and possible protective material for the bacteria) were investigated. In terms of the ECO-CEMENT process, the mixing, the curing (temperature, humidity and lime water conditioning) were evaluated. While the ECO-CEMENT pre-process was dedicated to nutrient substitutes for bacteria cultivation from dairy industry waste (whey and Mukki waste water) and further to the consolidation of the process (fresh culture vs. solid culture and reactivating on site).

Finally the ECO-CEMENT recipe was defined composed out of the binder CKD Bypur and RHA, the aggregate sand and biomass as liquid composite. Finally, The ECO-CEMENT cementation parameters (including the pre-processing) like cultivation of the bacteria, mixing and curing conditions were fixed.

The last **Task 3.5** was about studying the strength development through cementation trials and Smart Model Simulation Software implementation. A comprehensive study on optimizing the ingredient parameters concluded on a new recipe that results on a product with increased strength and resistance (see Deliverable report D3.37).The experiments performed, used varying amounts of biomass that contained urease enzymes and were activated using varying concentrations of urea solution. Subsequently the enzyme solution was used with CKD, a hydraulic agent (RHA) and aggregates (sand) to produce concrete blocks of specific dimensions. The amounts of these parameters were also varied and a series of samples were manufactured. The samples were poured into 5 cm x 5 cm x 5 cm blocks and allowed to cure under standard conditions.

Unconfined compression crush tests were performed according to E105-86/14 standard using a deformation control compressive strength machine. The strength and strains were evaluated from the initial zero load step until failure of each specimen. The stress strain curves were calculated for each load step using sufficient increments to identify yield and unload conditions. The data received were used to study the correlation between recipe parameters (biomass, CKD, RHA, sand, urea, water) and final strength.

From the data received it is not easy to make an obvious conclusion on an optimized recipe for maximum strength. This observation drove us to perform a refined stochastic analysis of the results. In particular, for each variable we sorted the results, and then classified them for 6 regions (where the variable values are quite similar) and the calculated the median value of this variable. Subsequently, we correlated this variable with the compressive strength and found significant enhancement at the R^2 value for this correlation (regarding medians). Therefore, we were able to define an optimum value for each variable and as a result an optimum recipe using the mechanical properties of the resulting material as criterion.

Table 2: Optimized Recipe for Eco-Cement

Optimal Percentage Biomass	Optimal Percentage Cement Kiln Dust	Optimal Percentage Rice Husk Ash	Optimal Percentage Sand	Optimal Percentage Urea	Optimal Percentage Water	Total
0.63	34.16	8.48	18.63	1.40	36.70	100.00

The cementation process described above evaluated a series of parameters in hopes of concluding on the most optimal recipe using strength as criterion. Despite of detailed studies an obvious first conclusion could not be reached. An optimal recipe was derived only after detailed analysis using a Gaussian model.

The main conclusions within the work of WP3 achieved are listed below:

- Whey and the wastewater used for cleaning production systems of dairy industry (Mukki Latte), could be efficiently used as alternative nutrient source for the cultivation of the bacteria
- Substitution of the expensive pure grade urea (as substrate for the urease) with the cheap fertilizer urea was successful
- The PAV type poultry manure is a suitable substrate for dry maintenance for at least 6 months of the *S. pasteurii* biomass and for the reactivation of the bacterial biomass when needed
- Eco-Cement is composed out of the binder CKD Bypur and RHA, the aggregate sand and biomass as liquid composite.
- The pH and the temperatures of the Eco-Cement mixture are critical for the bacteria but a high pH is required for the chemical process
- The bacteria are able to overcome the extreme alkaline condition when the biomass is consistent, remaining alive at pH higher than 12, and with an enzymatic activity very reduced, but not repressed.
- The results of first tests with the drilling machine indicate a hardening gradient within the bricks.
- The use of nutrient substitute whey gave no good results for whey when directly integrated in the process (if used, then just in pre-process and afterwards dried)
- Mixing of the Eco-Cement while preparation gave better results for slow mixing mode (less bubbles)
- Curing mode was defined best for room temperature and not wetted specimens while curing
- EDX indicates significant differences of the samples of each component (e.g. between Indian and Italian RHA Quality)

A series of samples were manufactured and mechanical properties were recorded using crushing tests.

3.3 WP4.- Tech. Syst. Int. and Smart Monitoring for an effective Indust. Application of EcoCement production. (ESS)

WP4 objective was to test the ECO-CEMENT product in an industrial application (priority was given to a construction application case). The demonstration stage took place during 6 months. The main idea was that it could provide replicability for other construction around EU with the new ECO-CEMENT product concept. It allowed us to quantify the global net reductions for energy consumptions, use of resources, raw materials, and waste production compared to the CO_2 emissions for the whole cement production cycle. The technological deployment was done in short time seeking the minimum possible impact in normal plant operations.

Results and conclusions obtained are shown below

- To develop and implement the "Smart model software": With the term "smart model" we mean the "smart" – mathematical and computational "model" – simulation of the influence of eco-cement recipe ingredients to the ultimate compressive strength of the trials. We assume that the 6 eco-cement recipe ingredients are the independent variables affecting the strength when their ratio in the final mix changes. Thus, the maximum resistance in uniaxial compression (σ_C) becomes the depended variable. Because eco cement is a new material, the mathematical formulation connecting these 6 ingredients with the final strength is unknown, so in order to formulate a simulation of the behavior of the trials in terms of final strength we performed this "smart model". In particular in WP3 a first trial to investigate possible correlations was done. In this work a simultaneously variation modeling of the design variables (six ingredients) was assumed. The correlation with final strength was initially attempted using traditional regression analysis, but because correlation factors and tests were not satisfactory, an advanced model using neural networks was implemented. Various parameters of the neural network training (determination) were investigated and an optimum one (in terms of mean square error) was found. Finally we used this artificial neural network to predict an optimum recipe, using compressive strength as criterion.

- Execution of ECO-CEMENT industrial application: For the pilot scale demonstration the following products were used; Fresh *Cement Kiln Dust* (CKD), extracted from the by-pass dust stack was used. The bacteria selected were *Sporosarcina Pasteurii*, which produces Urease, and it was fed with *Dairy industry by-products* as nutrients. Urea is obtained from fertilizers. As a source of silica to increase the hydraulic component of the mix, Rice Husk Ash (RHA) was applied.
  In the soil stabilization process, loose sand or gravel was converted into stone by injection of a dedicated mixture in the underground, which stimulates micro-organisms to catalyze chemical reactions leading to the precipitation of calcium carbonate ($CaCO_3$) crystals. These crystals form sticking bridges between the existing grains, increasing the strength and stiffness of the material. Reaction takes place at a controlled rate and over reaction distances of 5-10 meters. The large distance allows a much lower amount of injection wells and treatment underneath existing constructions which are difficult to access. The process can be repeated and reversed if

necessary. Strength and stiffness can be controlled; more CaCO3 simply leads to more strength, while the permeability does not decrease significantly. Hence, it is an efficient solution to:

- Reinforce embankments
- Prevent liquefaction and its damage
- Reduce building settlement and increase bearing capacity for foundations
- Stabilize the soil prior to tunneling (in order to reduce disruption and increase efficiency)
- Increase resistance to erosive forces of water flow (piping or surface erosion)
- Provide additional stability needed to stabilize slopes
- Sand production in oil or water wells (sand control)
- Create barriers that treat and clean groundwater as it flows
- Immobilize materials in the soil to prevent contamination of aquifers
- Create subsurface facilities for storage of liquefied natural gas or CO2
- Stabilization of gravels formation

Several successful pilots had been carried out, from 1 m^3 up to 100 m^3 with different types of soil materials. For example, 40 m^3 of loose sand have been bio-consolidated within 12 days reaching unconfined compressive strength up to 12 MPa[1]. Therefore, this process has been well studied and documented and has led to several patents[2] during the past few years.

The possibility to convert sand to sandstone by the use of bio-calcifying bacteria, such as *Sporosarcina Pasteurii,* has been probed at a pilot scale by several research groups across Europe. Moreover, the ECO-CEMENT consortium has the expertise and the technology to reproduce this process, either at a pilot or at a laboratory scale, with certainty of success.

As resources and time are limited in this project, our decision was to concentrate in other ECO-CEMENT applications; Tiles; Plaster and Bedding Mortar, which have never been piloted in a real case study. Whereas the Tiles have been extensively assessed by our colleagues from Neapolis University, this report focused in the study of the other two applications, which are:

- *Plaster: Covering a plaster layer of 1 cm thick and a surface of 1 square meter.*
- *Bedding mortar: Building a brick wall (brick dimensions 20x10x5 cm) composed of a column of 4 bricks length and 4 brick height (mortar layer thickness 1 cm).*

The next series of pictures illustrate the demonstration process as well as the resultant pilot cases: plaster mortar and a small brick wall.

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[1] http://www.deltares.nl

[2] Van Passen L.A., Whiffin V. and Harkes M.P. (2007). Immobilization of Bacteria to a geological material; stichiting Geodelft/Deltares, patent WO2007069884A1
Latil-Collinet M.N.L. and W.H. Van der Zon (2009) A method for avoiding or reducing permeation of soil particles in a hydrocarbon well. Stichiting Deltares, patent W02009/008724

Figure 9: Urea BSS solution added to inorganic components

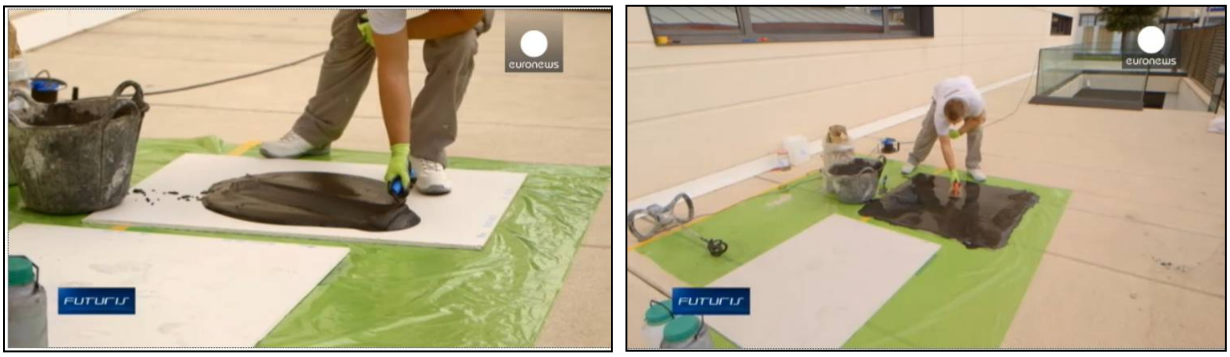


Figure 10: Board covered with plaster

Figure 11: Brick wall

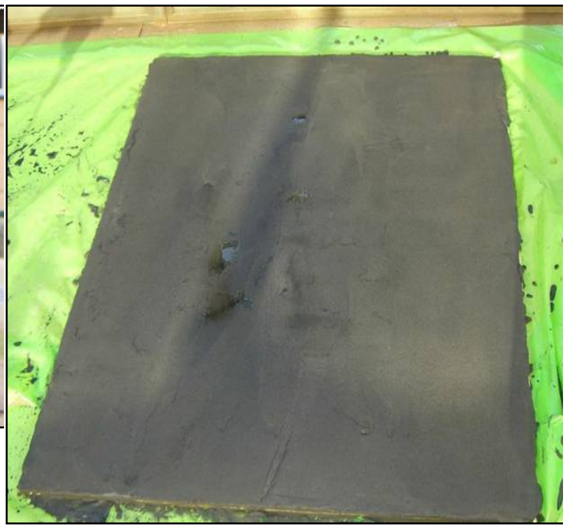


Figure 12: Board covered with rendering plaster

- To verify the properties of ECO-CEMENT in order to replicate the experience in other construction sites around EU: Samples of ECO-CEMENT were collected in order to be tested at a laboratory scale, where their suitability to be used as masonry and rendering mortar was assessed. Samples of the ECO-CEMENT material were prepared and tested in order to verify its degree of compliance with the international standards; EN 998-1: 2010 and EN 998-2: 2010.

  The analysis was repeated at 7 and 28 days of curing. The final results were obtained on the 23rd of January 2015. According to these results, ECO-CEMENT has the following properties and could be applied for the following uses:

  - Rendering mortar (UNE EN- 998-1) obtained had the following characteristics: **GP CII WO**
    - Compressive strength: 2.6 N / mm^2; Type CII
    - Water absorption by capillarity: 10.3 kg / m^2 0.5 min; W0
    - Bulk density:1.53 g/cm^3

  Therefore, it presents the following utility features: inner liners which do not require resistance to filtration, as capping layers and / or partition and interior plaster sheets. In addition it can be used for the rehabilitation and restoration of historical works, as it does not contain Portland cement.

  - Masonry mortar (UNE EN-998-2), **Type M 2.5** useful either for standard or fine joints applications, equally suitable for internal uses or without structural reinforcements, applications that do not involve isolation. Indeed, it could be used for parts terrazzo, cement tiles, etc., in short simple extension screeds.

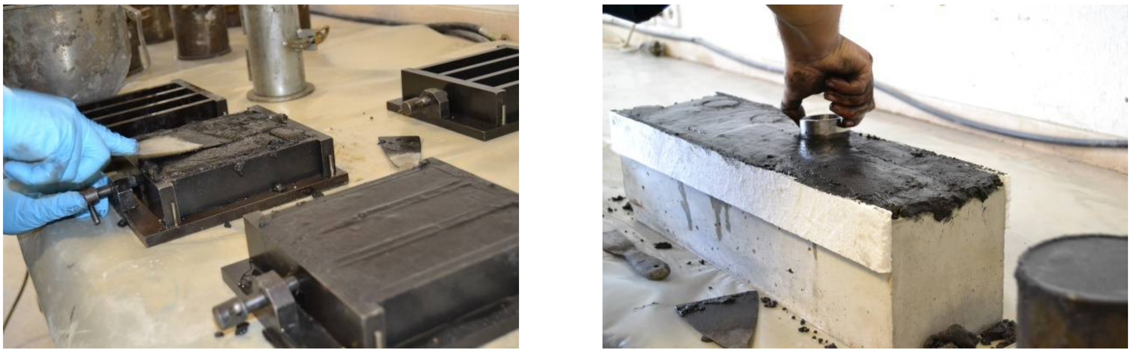


Figure 13: Preparation of samples.

Figure 14: Workability test

Figure 15: Penetration test

3.4 WP5.- Data Analysis, Validation and Life Cycle Assess. for a less polluting and resource intensive product.

The first significant achievement in WP5 was the use of the LCA methodology to identify that one of the key ingredients in the Eco-Cement process, fertilizer grade urea, had a very significant negative environmental impact because it was made from, and with, natural gas. The impact was so significant that the LCA analysis demonstrated that an Eco-Cement made with fertilizer grade urea would have a greater environmental impact than OPC and could therefore never be called an “Eco” cement.

The second achievement was to identify a process that could create urea with a positive environmental impact. We found that a bio-gas made from the pyrolysis of waste wood biomass has the same chemistry as natural gas and could be the precursor for the creation of a bio-urea using the same Haber-Bosch process as is used to make fertilizer grade urea.

One of the first steps in an LCA analysis is to set the boundaries of the LCA assessment and we set them as wide as possible using the principle of ‘cradle to cradle’ to capture the complete life cycle of all the impacts of the process. There are three valuable by-products of the pyrolysis process: bio-gas, bio-char and bio-oil. The LCA showed that these by-products had very positive environmental impacts which contribute to the overall positive environmental impact of the final Eco-Cement process. It is an achievement to be able to demonstrate that the overall Eco-Cement process has a positive environmental impact and that it permanently sequesters carbon in the soil to improve fertility and displace fertilizer grade urea used in agriculture.

The LCA methodology requires a detailed Life Cycle Inventory of all the ingredients of Eco-Cement. This analysis enabled the selection of ingredients with comparatively lower environmental impacts such as RHA. Rice Husk Ash is a waste that proved to have such a positive environmental impact that it was considered to be the best choice for a pozzolanic waste in the recipe.

We consider it an achievement that we were able to use the LCA methodology proactively, and we believe innovatively, as a design tool to select ingredients with lower environmental impacts and to develop an integrated sustainable process with valuable by-products. The methodology was used to make decisions and was not just used to analyse the final recipe and process.

The LCA for Eco-Cement was compared to LCA’s we completed for OPC and GGBS cements so that we could justify its definition as an ‘Eco’-Cement. The results demonstrate that Eco-Cement has an environmental impact which is 90% lower than OPC and 80% lower than GGBS.

Based on the LCA a complete EPD was created for Eco-Cement so that comparisons with the EPD’s for other similar products could be made using the same or similar criteria. The EPD is a useful marketing tool and it clearly shows why Eco-Cement has a lower environmental impact when compared to the EPD’s for OPC and GGBS.

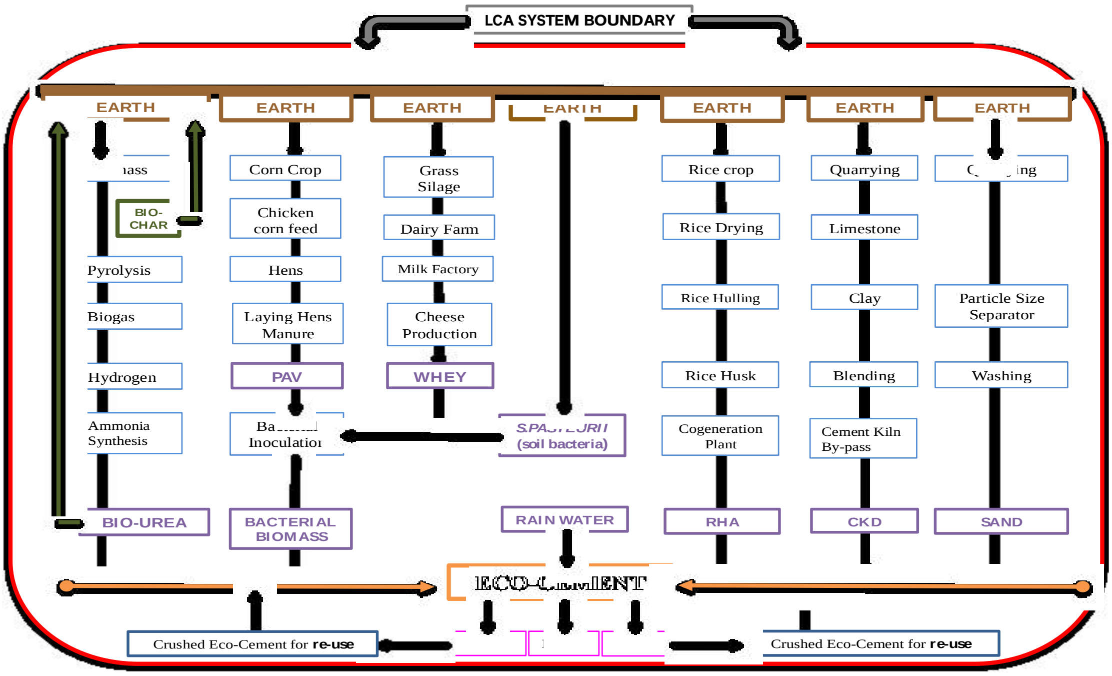


Figure 16 LCA system boundary using cradle to cradle principles

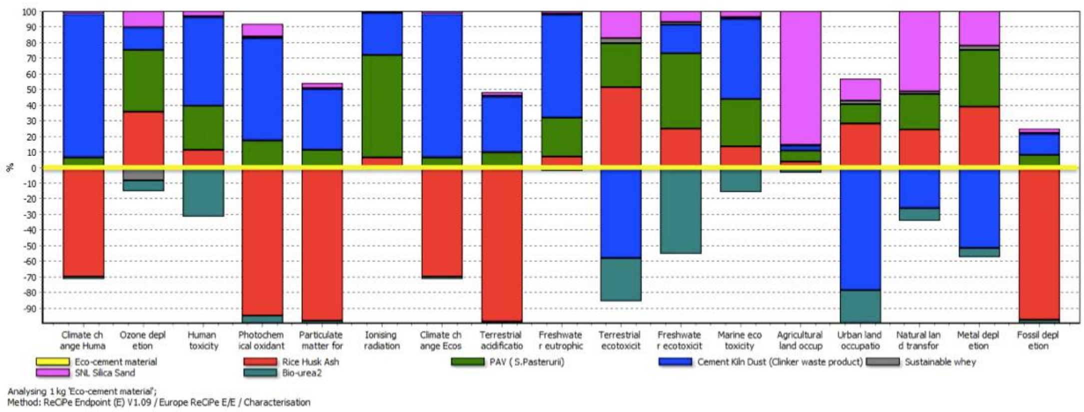


Figure 17 Environmental impact of key ingredients using LCA KEPI's

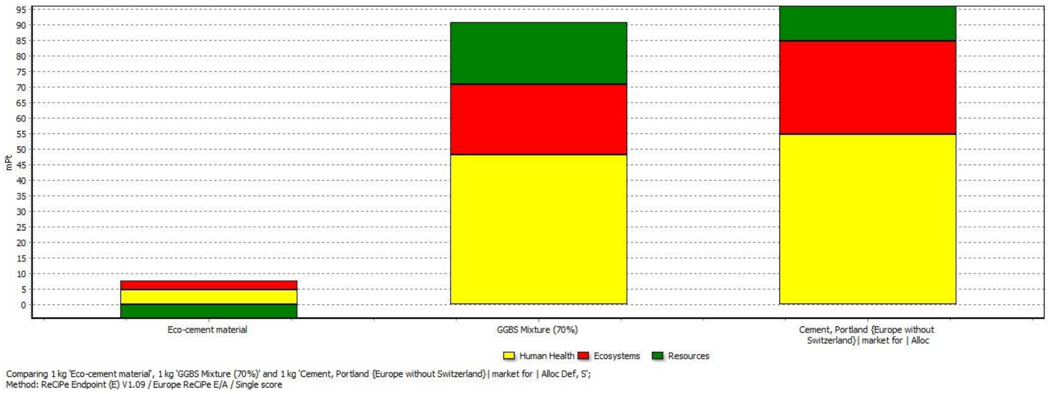


Figure 18 Overall environmental impact of Eco-Cement compared to GGBS and OPC

Impact Category	Unit	Eco-Cement	OPC	GGBS
Global warming	KgCO2eq	5.44	899	4.16E+01
Ozone Depletion	Kg CFC-11 eq	1.14E-06	0.000043	5.08E-06
Photochemical oxidation	Kg C2H4 eq	-0.0116	0.25	2.89E-02
Acidification	Kg SO2 eq	-0.336	2.4	4.60E-01
Eutrophication	Kg PO4	0.0176	0.25	4.44E-02
Mineral , Fossil and resource depletion	Kg Sb eq	0.000422	----------	3.30E-01

Figure 19 EPD comparison between Eco-Cement, OPC and GGBS

3.5 WP6.- Business/Market Modelling, IPR Strategies and Exploitation of Project Results

WP6 achieved a strong and practical Exploitation Plan which the partners will be able to use immediately following the end of the project. There were five main exploitable results which the partners are interested in pursuing:

1. DRIED BIOMASS PACK can be exploited by CNR-ICBVC
2. TILES can be exploited by CNR-ICBVC
3. MORTAR can be exploited by CNR-ICBVC
4. PLASTER can be exploited by CNR-ICBVC
5. TRAINING COURSE can be exploited by Neapolis University.

The exploitable benefit of the project for the two SME's involved in consultancy work, Solintel and DWEcoCo, is the knowledge and additional experience gained in the field of LCA assessments and the use of industrial wastes.

The main achievement of the continuous industry watch and research into the emerging field of bio-cementation was the knowledge that there is significantly increased research activity and interest in this field since 2005. The main actors in this field were identified and by using innovative patent landscaping research strategies it was possible to analyse who, what, when, where and why the research work in this field was being done. A significant conclusion is that the knowledge gained in this Eco-Cement project is valuable to the cement industry and the fracking industry.

This analysis of bio-cementation research highlights that other researchers which use urea to activate bacteria in a bio-cementation process have not assessed the environmental impact of conventional fertilizer grade urea, yet they claim their process has a low environmental impact. We could find no mention of this aspect of urea in the published material so we consider our solution to this issue to be a unique achievement of the project.

The achievement of the research into the costs of producing Eco-Cement indicate that it can be sold at a profit at a price that is 20% cheaper than OPC. If this profitable business opportunity was adopted by the 200 OPC plants in Europe it would create at least another 2,000 new jobs and significantly lower the environmental impact of those OPC plants.

The most significant achievement of WP6 is the business model for the production of Eco-Cement which shows an IRR of 82%, an NPV of **€695,876,350** on an investment of €97M and a simple **payback period of 1.3 years.** The business model is a good example of the potential of a sustainable business which uses the principles of a circular economy which predominantly uses industrial 'wastes' as raw materials and renewable energy to fuel the whole process.

The holistic, systems thinking approach used throughout the project has led to an "integrated Eco-Cement industrial ecological system" of interrelated processes and by-products which use a number of waste streams to produce an "**Eco-Bio-Cement"** with an environmental impact which can be lowered further by increasing the volume of by-products produced. The production process becomes increasingly profitable as the scale of production increases while at a small scale it remains financially very attractive.

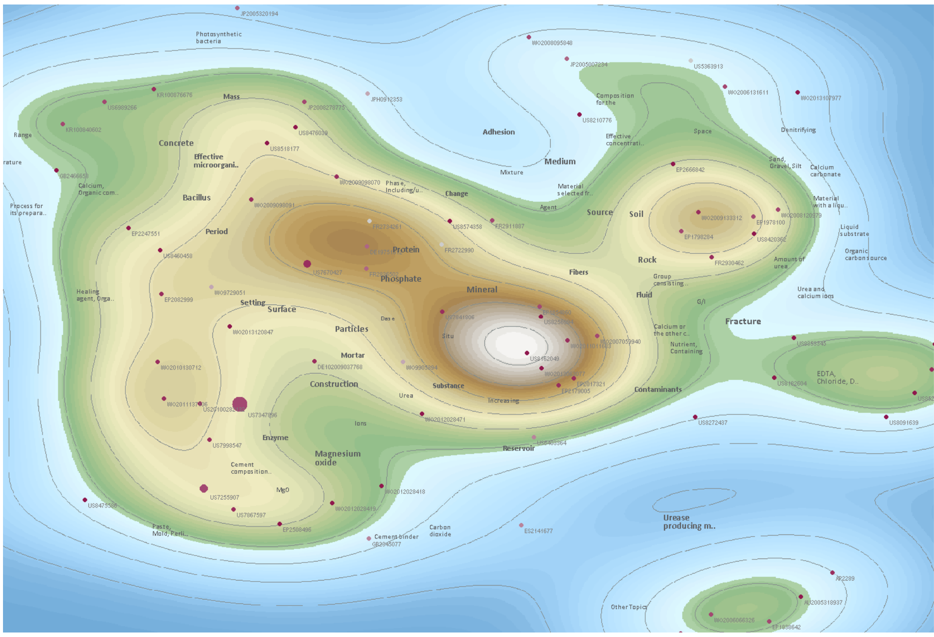


Figure 20 Patent Landscaping Themescape

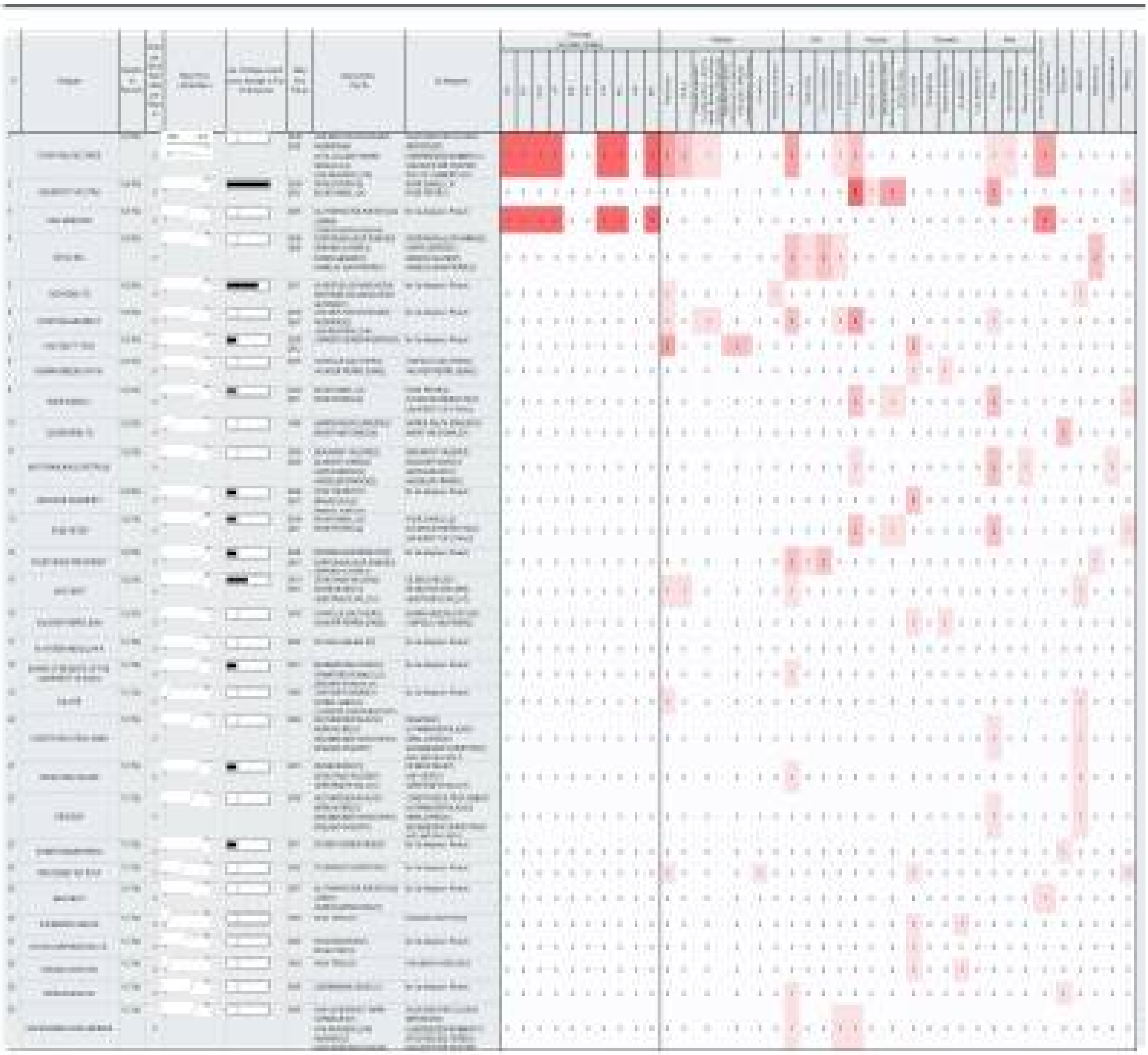


Figure 21 Summary Table of Top 30 Patent Assignees

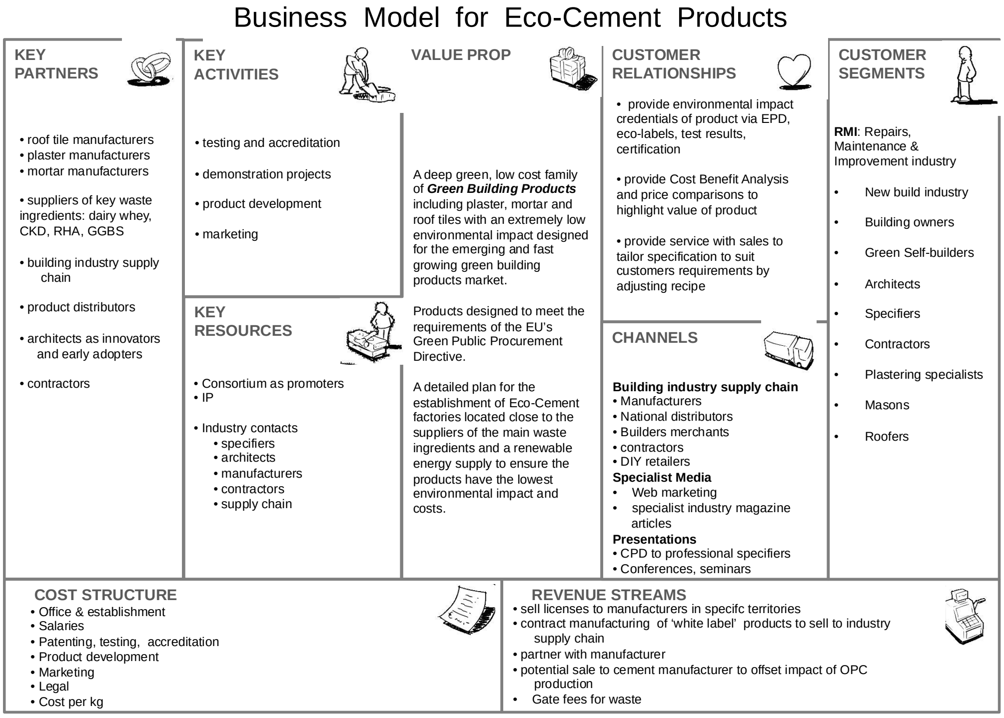


Figure 22 Business Model Canvass for Eco-Cement

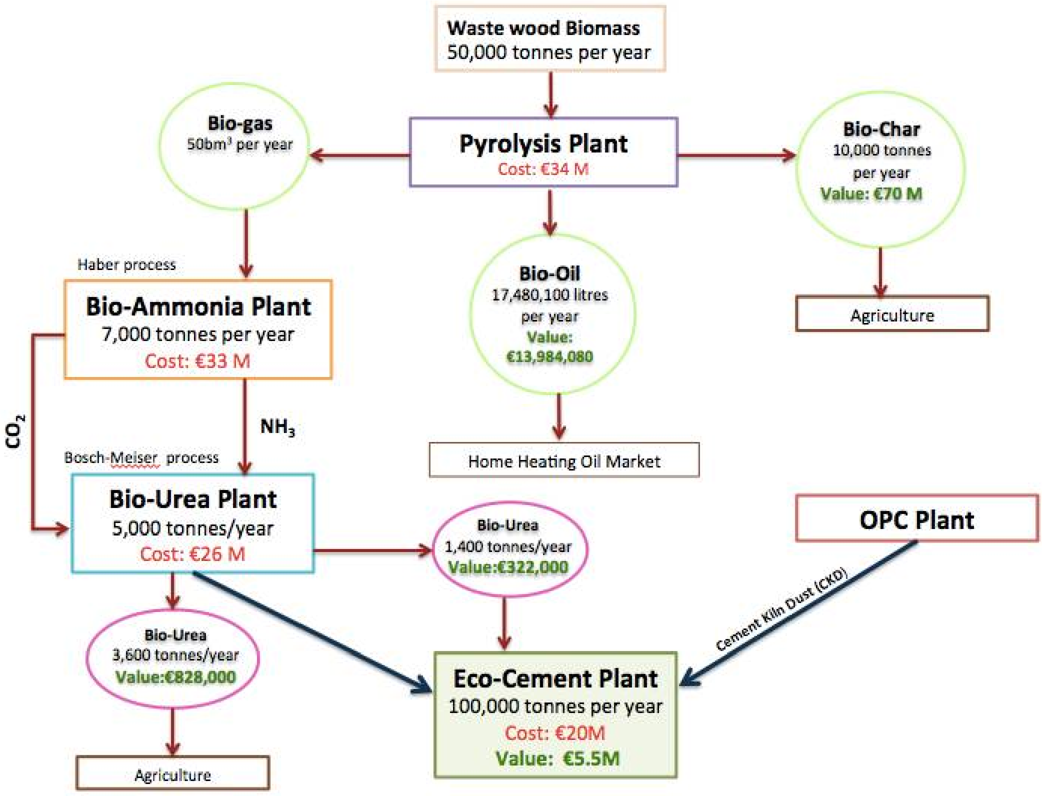


Figure 23 Eco-Cement Production: An integrated system of Industrial Ecology

Feedstock = 550,000 tonnes per year	
Eco-Cement Material Costs (All (material inputs)	€ (313,121)
Total Production Cost (Labour, Operations, Maintenance, Utilities, Administration costs for all process plants)	€ (77,635,220)
By-Product Profit (Bio-gas, Bio-char, Bio-oil)	€ 782,230,000
Eco-Cement Profit (€55 per tonne)	€ 5,500,000
Annual Net Profit	**€ 709,781,659**
Total Capital Investment (Pyrolysis Plant, Bio-Ammonia Plant, Bio-Urea Plant, Eco-Cement Plant)	€ (796,352,200)
Simple Payback Period (Years)	**1.1 years**

Table 3 Summary of Costs and profit of a large scale Eco-Cement Production Plant

4 DESCRIPTION OF THE POTENTIAL IMPACT, THE MAIN DISSEMINATION ACTIVITIES, AND THE EXPLIOTATION OF RESULTS.

4.1 Potential impact.

4.1.1 Economic impact.

The expected economic impact of Eco-Cement was outlined at the beginning of the project and the achievement of the project is summarised in the table below against this target. The cost of OPC cement was about €70/T in 2011 and it was expected that Eco-Cement would cost less to make and could be sold competitively at €55/T. The actual cost of production has now been estimated to be €23/T which means that with a sale price of €55/T there would be a profit of €32/T.

Eco-Cement is 3 times more profitable than OPC to manufacture which is estimated to generate a profit of only €10/T.The profit margin of Eco-Cement is 58% whereas the profit margin on OPC is 14%. This creates the opportunity to further reduce the sale price of Eco-Cement to make it extremely competitive and attractive in the market. This may be necessary in the early stages of commercialisation when market resistence is at its highest with a new material and product range. The “S-Surve” of growth for innovation means a pricing strategy which follows the S-Curve of market penetration would be very useful. Fortunately the costs of production support such a pricing strategy.

It also creates the opportunity to increase the strength of Eco-Cement by adding micro-fibres or other ingredients which will increase the production costs while not making the Eco-Cement unprofitable. In other words there is enough profit margins to allow further development of Eco-Cement to increase its usefulness in the market by increasing its strength, durability and other criteria that the market will want.

This calculation of the production costs of Eco-Cement at €23/T does not take into account the value of the by-products created by the entire process developed within Eco-Cement. The combined value of the Bio-char, Bio-urea and Bio-oil that are also produced in an integrated Eco-Cement plant can offset completely the €23/T production cost of Eco-Cement and reduce it to zero. Thus the economic impact can be very significant if this business model is adopted by the investor, who we suggest is ideally the cement industry itself.

If the Business Model sets the production costs of Eco-Cement at zero then whatever price it is sold for is 100% profit. This will support continued self-funded research and development of the process and product so that the technology matures and becomes widely adopted.

4.1.2 Social impact:

The social impact of the expected adoption of Eco-Cement production by the cement industry could lead to the creation of at least 2,000 new jobs across Europe. This estimate of the number of jobs is based on the conservative assumption that relatively small Eco-Cement plants producing 100,000 T/pa are established by the cement industry immediately adjacent to their existing OPC cement plants. The cement industry is consolidating and the number of cement plants has been reducing since 2000 with mergers and acquisitions in the industry. Our job creation estimate is based on the current estimate of 200 OPC plants in Europe.

The jobs created could increase significantly if the Eco-Cement technology is further developed as outlined above. As market share increases along the S-Curve of market share and product development then it is very possible that larger plants will be developed to produce a wider range of products as the product becomes stronger and achieves greater functionality. This is likely to happen outside the 10 year timeline of these expected impacts so we have not included any estimates of this far greater potential.

4.1.3 Environmental impact:

The very low environmental impact of the Eco-Cement process and products has been detailed in the LCA assessment and WP5 report. The metric that is most often used to measure and compare environmental impacts is “carbon dioxide emissions” which is generally referred to as ‘carbon emissions’ and stated in kg CO_2/kg. The average global CO_2 emissions for OPC cement was 0.81 kg CO_2 / kg cement in 2011. The target for Eco-Cement was a combined average CO_2 emissions for OPC plus Eco-Cement assuming they were produced by the same “company or plant”. This target was estimated to be 0.72 kg CO_2/kg OPC + Eco-Cement.

The LCA analysis completed in WP5 concluded that the CO_2 emissions of Eco-Cement on its own were just 0.00705 kg CO_2/kg Eco-Cement. If we assume combined average of OPC and Eco-Cement and use a simple 50:50 sample then the combined average CO_2 emissions are just 0.409 kg CO_2/kg OPC/Eco-Cement. Considering either result the environmental impact of Eco-Cement is much lower than the target set at the beginning of the project.

Eco-Cement only uses CKD from the cement industry and not other wastes from the construction industry as was originally envisioned at the beginning of the project. The target of increasing the amount of recycled aggregate from the construction industry is therefore not achieved. However the use of RHA waste, waste whey from the dairy industry and waste biomass in the overall Eco-Cement process is a significant use of waste streams from other industries with a positive impact on the environment which is captured in the LCA assessment.

4.1.4 Energy Use impact.

The impact on energy use by the production of Eco-Cement is very significant and exceeds the target estimates made at the beginning of the project. The high temperatures required for the production of OPC cement is the major factor in its high energy use, ‘carbon footprint’ and negative environmental impact. In 2011 the average electricity consumption for OPC was 111 kWh/T The target in the project was to reduce this to 16 kWh/T Eco-Cement

The estimate of electricity use for an Eco-Cement plant is 15 kWh/T Eco-Cement as the major electricity use will be in handling and mixing the bulk ingredients in the factory building. In a 100,000 T/pa plant this is an achievable target.

It is important to note that the proposal for an integrated Eco-Cement plant includes using waste wood as the source of renewable energy. The most efficient process to extract energy from biomass is via pyrolysis which is required to create the bio-gas precursor for the bio-urea. The amount of biomass used in the pyrolysis process can be increased to produce sufficient bio-gas to be used as the fuel for a CHP / co-generation plant which will supply the electricity and heat required in the whole Eco-Cement process. Thus the 15 kWh/T of electricity will be renewable electricity produced at low cost by the Eco-Cement plant.

The low temperature of 30C required for the Eco-Cement plant results in a thermal energy requirement of just 0.647 GJ/T Eco-Cement. This is significantly lower than the 3.7 GJ/T required fro OPC production and the 3.1 GJ/T target expected at the beginning of the project. This low temperature can easily be achieved using the renewable heat generated by the CHP / co-generation plant fuelled by the bio-gas from pyrolysis.

4.2 Main dissemination activities.

Dissemination activities cover all the range of actions that contribute to the availability of the project results for potential stakeholders. Starting point for the development of a suitable dissemination plan is the identification of potential stakeholders who we consider to be potentially influenced by the results of the projects and who will benefit from the project's outcomes. The main areas addressed were defined by partners in WP7 in order to improve an effective and constant ECO-CEMENT communication and dissemination policy.

ECO-CEMENT key messages were defined as follows, focusing mainly in the production of the new type of ECO-CEMENT:

- Use of cement industry waste, specifically solid alkaline waste, as raw material for the production of ECO-CEMENT.
- Application of a bio-mimetic process for the production of ECO-CEMENT.
- Energy saving, waste revalorization and reduction of emissions of ECO-CEMENT.

During the course of the project, the ECO-CEMENT partners have carried out clustering activities with European related projects from FP7 (Environment, Transport, ICTs), Eureka (EUREKABUILD, PRO-FACTORY, LOGCHAIN) and the related European and National Technology Platforms (ECTP).

A stakeholder list has been prepared for each country participating in the project. It has been used first of all in order to inform them about the Ecocement project concept, and also about the results achieved within the project.

The architecture of the ECOCEMENT brand is based on the following tools (available at the project website):

4.2.1 Project Presentation.

An ECO-CEMENT Project Presentation has been the part of the different dissemination tools designed to support the ECO-CEMENT dissemination efforts. This task includes a presentation template and a project presentation. The template is to be used in all events and meetings where ECO-CEMENT results and activities are presented. It has been designed following the graphic identity guidelines to facilitate the recognition of the project. The ECO-CEMENT project power point presentation provides a general project overview, background information, objectives, rationale, partners and first results. This presentation is available in project website.

4.2.2 Leaflet

The leaflet is a non-electronic dissemination material to be distributed during conferences, workshops and during general project events. The main objective of the leaflet is to provide our audiences with an attractive and written project overview with a summary of the main project objectives and characteristics. The ECO-CEMENT leaflet was prepared within WP7 activities.

4.2.3 Project short paper.

A project short paper document will be developed presenting at one glance general project facts, objectives, target groups and contact details. It further will follow the defined graphic identity of the project and serves as an additional dissemination material to support the project's dissemination activities. The short paper will also be made available on the ECO-CEMENT web site.

4.2.4 Poster.

The main purpose of the poster is to catch the audience attention. To reach this objective an eye catching poster have been designed. With regard to the layout and design, the poster shows the project's logo and the ECO-CEMENT colours emphasizing the link to the project's graphic.

The poster has been used in workshops, conferences and other events as a presentation of the project where the consortium partners participate or hold the event. It is complementary to the leaflets, since the latter provide more detailed information about ECO-CEMENT

4.2.5 Newsletter.

The ECO-CEMENT newsletter offers an appropriate means to carry out direct proactive communications to the targeted stakeholders and the European Commission. Three numbers have been published, sent by e-mail and posted in the ECO-CEMENT web site.

4.2.6 Publication of reports.

ECO-CEMENT is an open project and we expect the research results to have a large impact on the European construction sector. Public Deliverables are available in project website.

4.2.7 Participation at Conferences and Fairs

One of the most important dissemination parts is the dissemination that had been achieved through scientific and technical presentations in international conferences, congresses, exhibitions fairs and workshops. Conferences are important to be held since it is an efficient way to announce and present the ECO-CEMENT project and its concrete results of research to a wide audience. Attending selected events and workshops will allow the consortium to create awareness and attract potential stakeholders. The consortium members have presented the project concept and results in a number of different events as indicated below:

- ECO-CEMENT own events:

Table 4: List of ECO-CEMENT own events

WORKSHOPS			
Date/ Place	**Partner organizer**	**Topic**	**Participants**
SAIE – Bologna (IT) **24.10.2014**	**NEAPOLIS**	Green building materials by using bioenzymatic calcite precipitation	Visitors of the SAIE Fair; Conference participants + the consortium
La Brilla – Pisa (IT) 26.02.2015	**CNR-ICVBC**	Green building materials by using bioenzymatic calcite precipitation	Public administrators, Building companies, Architects. Students + the consortium

- ECO-CEMENT external events:

Table 5: List of conferences and workshops

EVENTS CALENDAR				
DATE/ PLACE	EVENT	PARTNER PARTICIPATING	TYPE OF AUDIENCE/ FOCUS OF EVENT	CONTACT INFORMATION
02.05.2012	**Techno Heritage 2012**	**CNR-ICVBC**	Promote networking among European research	http://www.technoheritage.es/Santiago.html

EVENTS CALENDAR				
DATE/ PLACE	EVENT	PARTNER PARTICIPATING	TYPE OF AUDIENCE/ FOCUS OF EVENT	CONTACT INFORMATION
	International congress on Technology for the conservation of cultural heritage Santiago de Compostela [Spain]		teams and strengthen the foundation of scientific and technological research, overcoming the barriers of exchanging information on coordinated research applied to the protection of tangible cultural heritage in Europe.	
14.01.2013 19.01.2013	**BAU 2013 World's leading trade fair for Architecture, Materials and Systems** Munich [Germany]	**IFAM**	Business, contacts and information platform for all professionals involved in building design, construction and management	http://www.bau-muenchen.com/en/Home
09.05.2013 10.05.2013	**2nd Global CemTrader Conference** London [UK]	**DWEcoCo**	Covers all aspects of the cement industry: mining and quarrying, refractories, process optimisation, monitoring, alternative fuels, environment and safety, markets, trading and shipping and a full review of global cement news.	http://www.globalcement.com/conferences/global-cemtrader/past/gct-2013-review
21.07.2013 25.07.2013	**FEMS 2013 The 5th Congress of European Microbiologists** Leipzig [Germany]	**IFAM**	FEMS 2013 addressed the many challenges facing key areas in microbiology. Topical coverage of medical microbiology including molecular approaches, as well as biodiversity, bioremediation, Symposia and workshops lead by prominent scientists	http://www2.kenes.com/fems2013/pages/home.aspx
12.08.2013 15.08.2013	**12th SGA Biennale Mineral deposit research for high-tech world** Uppsala [Sweden]	**CNR-ICVBC**	Exchange knowledge within the field of mineral deposit research. Researchers, managers, and scientists in the field.	www.conference.slu.se/sga2013/

EVENTS CALENDAR				
DATE/ PLACE	EVENT	PARTNER PARTICIPATING	TYPE OF AUDIENCE/ FOCUS OF EVENT	CONTACT INFORMATION
08.09.2013 13.09.2013	**EUROMAT 2013 European Congress and exhibition on advanced materials and processes** Seville [Spain]	**IFAM**	Held every two years since 1989, Euromat gathers academics and researchers from the industry with a large scope on material science and technology and their application	www.euromat2013.fems.eu/welcome.html
13.03.2014	**INTERNATIONAL FAME LAB WORKING SCIENCE** Nicosia [CYPRUS]	**NEAPOLIS**	The national talent competition which tries to find the best new talent in science communication. Its aim was to encourage scientists, engineers, technologists and mathematicians to inspire and excite public imagination with a vision of science in the 21st century.	NEAPOLIS UNIVERSITY
28.10.2014 30.10.2014	**World Sustainable Building Conference 2014** Barcelona [Spain]	**SOLINTEL**	The WSB 2014 Conference is the largest meeting on a global level on sustainable building where the most important and influential international institutions, experts in this field, will meet	www.wsb14barcelona.org
10.01.2015 11.01.2015	**ICEBE 2015** International Conference on Environment and Bio-Engineering DUBAI [UAE]	**CNR - ICVBC**	Provides a platform for researchers, engineers, academicians as well as industrial professionals from all over the world to present their research results and development activities in Environment and Bio-Engineering.	http://www.icebe.org//

- Demonstrations

The partners have been performed two practical demos for validating and summarizing the achieved project's results.

- **Madrid (Spain)** on 26/09/2014, at the Essentium's premises
- **Pisa (Italy)** on 26/02/2015 at the Brilla , Massarosa

4.2.8 Educational and training courses

The NUP partner, in collaboration with the others ECO-CEMENT members has elaborated a training e-course for university students.

4.2.9 Guideline for the assessment of policy instruments

The guideline for the assessment of policy instruments have been framed into the international and regional provisions and standards regarding: (i) the institutional framework for environmental protection in industrial production, (ii) the management of industrial waste, (iii) methods of standardization of cement.

The production of eco-efficient environmental cement through the revalorization of industrial waste that is the main objective of the ECO-CEMENT project should be based on meeting a series of legislative parameters:

- Modern concepts of environmentally friendly production should be met.
- Management of industrial waste from cement production should be consistent with existing legislation.
- The mechanical and physical properties of the cement should meet international standards in order to be considered as an improved version of other cement types already in use.

The list of legal framework associated with the industrial production of cement have been referred to some of the foremost international bodies such as CEN, ISO, ASTM and US-EPA and cover both environmental issues related to the production process, and methods of quality certification of the produced cement.

4.2.10 Final sets of policy briefs

This document presents ECO-CEMENT policy brief, which outlines the rationale for selecting ECO-CEMENT against its competitors. The purpose of this brief is to present the findings and recommendations of the ECO-CEMENT project to a non-specialised audience and to convince the stakeholders of the opportunity to adopt the ECO-CEMENT in order to work on sustainable and environmentally friendly basis.

4.3 Exploitation of results

Five exploitable results were identified by the partners who expressed their interest in pursuing these:

Table 6: Results description

#	Exploitable result	Leader Partner	Type of result	Associated WP
1	Dried Biomass Pack	CNR-ICVBC	Product	WP3
2	Tiles	CNR-ICVBC; IFAM	Product	WP3
3	Bedding Mortar	CNR-ICVBC; IFAM	Product	WP3
4	Plaster	CNR-ICVBC; IFAM	Product	WP3
5	Training Course	NEAPOLIS	Knowledge	WP7

The partner's intentions to exploit these results were indicated and condensed in the MULO matrix below:

- IPR ON BACKGROUND INFORMATION (**B**)
  Information, excluding foreground information, brought to the project from existing knowledge, owned or controlled by project partners in the same or related fields of the work carried out in the research project. Only relevant information for the project can be considered background.
- IPR ON FOREGROUND INFORMATION (**F**)
  Information including all kind of exploitable results generated by the project partners or 3rd parties working for them in the implementation of the research project
- EXPLOITATION CLAIMS (**M, U, L, O**)
  The intention of the partners to exploit the results by:
  - Making them and selling them (**M**)
  - Using them internally to make something else for sale (**U**)
  - To license them to 3rd parties (**L**);
  - To provide other services such as consultancy,(**O**).

Table 7: Partner's preliminary exploitation intentions

Results / Partners	1. Dry biomass	1. Tiles	2. Bedding Mortar	3. Plaster	4. Training Module	5. Consultancy	PATENT LCA
GESS	FU	FU	FU	FU			
IFAM	FU	FU	FU	FU	FO	FO	
SOL	FO	F O	FO	FO	FM	FO	FO
CNR	FLMO	FLMO	FLMO	FLMO	FMO	FO	
NEAP	M	M	M	M	O	O	
DWE				FL		FO	FO

For each of these identified results an *Exploitation Questionnaire* and *Characterization Table* was prepared to collect as much information as possible regarding each innovative outcome. Each market segment was researched to establish the potential size of the market and current technology trends which affect the market segments. This information was used as the basis for the SWOT and PEST analyses for each exploitable result and its applicable market segment.

Table 8: ECO-CEMENT SWOT MATRIX

ECO-CEMENT SWOT MATRIX	
ECO-CEMENT STRENGTHS	**ECO-CEMENT WEAKNESSES**
The ECO-CEMENT project results indeed are relevant for the EC's energy efficiency targets and contribute to have an appropriate management of the wastes with the final aim of lowering the energy consumption and decreasing the CO_2 emissions, reducing the environmental burden	The cost of learning new methods of assessing systems. The time required to carry out analysis to create systems / a system which uses wastes as a resource purchasing and, transporting and processing wastes, Setting up new systems to move waste to site. Limit of budget to adopt new technologies
ECO-CEMENT OPPORTUNITIES	**ECO-CEMENT THREATS**
Financial incentives: Companies have a strong financial reason for cost reductions through the use of alternative raw material. Government support: Government policy and regulations that actively promote the application of systems thinking in industry. Waste management infrastructure deficiencies: The disposal capacity in landfills or incinerators is limited and alterative streams for "waste" flows needs to be investigated.	Security of supply: security of adequate waste supply. Attitudes to change: the perception of the difficulty of changing to a new way of working. Technical barriers such as the codes of practice in different areas of industry that need to be compiled with. Logistics: of re positioning / positioning industries adjacent to one another. Lack of awareness of market opportunities: inability to identify and capitalize on sources of waste in the region that could be useful processed. The economic crisis affected the number of companies; therefore, there could be few potential clients. Aggressive marketing policy from competitors Not sufficient resources from developers due to other responsibilities.

A detailed risk assessment was completed which is summarised in the following matrix:

Table 9: Risk assessment matrix.

Risks \ Groups		RESULT NUMBER:	GROUP NUMBER.			Comments
			Impact (I)	Likelihood (L)	Ranking (I x L)	
	Technological risks:					
1	Worthless result	The project lasted too long	1	1	1	The project needed more time
2	Worthless result	Ill-timed disclosure	1	1	1	Care has been taken to limit disclosure
3	Worthless result	Better technology / methodology exists	3	2	6	
4	Significant dependency on other technologies		3	2	6	Dependency on pyrolysis not a relevant problem as this is well known and not patented
5	The life cycle of the new technology is too short		2	2	4	
6	Result aiming at replacing existing and well entrenched technologies		1	2	2	
	Partnership risks:					
7	Disagreement on further investments: some partners may leave.		1	1	1	
8	Industrialization at risk	No manufacturer for the exploitable result	3	2	6	
9	Industrialization at risk	An industrial partner leaves the market.	1	1	1	
10	Industrialization at risk	A partner declares bankruptcy	1	2	2	
11	Disagreement on ownership rules		1	2	2	
12	Partners on the same market		1	1	1	
	Market risks:					
13	Exploitation disagreement	Partners on the same market	1	1	1	

14		Partners with divergent interests	1	1	1	
15	Worthless result: performance lower than market needs.		2	2	4	
16		Nobody needs it	2	2	4	
17		Too expensive	2	2	4	
18		Unsuitable sales force	2	2	4	
19		The project hits against a monopoly	2	1	2	
20	Nobody buys the product	Problems at the time of the first sales	3	2	6	Early production problems and early failures will need to be solved quickly or avoided by a large testing regime
21		Rejected by end-users	3	3	9	
	Legal risks:					
22		Proceeding against us	2	1	2	
23	Legal problems:	We are sued for patent infringement	2	1	2	Patent landscaping study ensures we know of competing patents to be avoided
24		It is easy to counterfeit the patent	3	2	6	This is a very large market
25	Know- how risks	A counterfeit cannot be proved	2	2	4	
26		The patent application is rejected	1	2	2	
	Management risks:					
27	Nobody buys the product. Our licensee is not exploiting his exclusive license		2	3	6	The promoters to invest in early manufacturing and demonstration projects to prove value
28	Know- how risks: there are leaks of confidential information		1	2	2	
29	Multiple change to original objectives		2	2	4	

30	Inadequate communication among partners		1	2	2	
31	On time supply of financial means		3	2	6	
32	Weak exploitation. Inadequate business plan		2	1	2	
	Environmental/regulation/safety risks:					
33	Nobody buys the product	Does not comply with the standards.	3	3	9	The current product has low strength. This leaves margin for improvement
34		Standards to make it compulsory don't yet exist	2	3	6	
35	Research is socially or ethically unacceptable		1	1	1	
36	Influence of laws and regulations		3	3	9	

A risk management plan was developed in response to the risk assessment which is summarized in the following table:

Table 10: Risk management plan.

Risk #	Major Risk (I x L ≥ 9)	Solutions and Actions
21	Rejected by end-users	• Clever dissemination policy, targeting policymakers, users and designers. • Seek to promote applications with the highest possible visibility • Monitor constantly the product technical performance • Explore alternative applications, to avoid depending on the success of a single market • Developing an adequate business model • Promote other advantages than cost (simplicity, focus on lifecycle, environmentally friendly aspects, etc.)
33	Does not comply with the standards	• Develop standards in parallel with market implementation, to ensure the standards are perceived as a help and not as an obstacle.
36	Influence in laws and regulations	• Involve standard bodies, by sending information / guidelines and leveraging membership to the companies involved in the sector.

A joint business approach was developed to consider an exploitation strategy for the Eco-Cement consortium to jointly exploit the results. This resulted in further segmentation into three areas which could be exploited. The fact that the consortium consists of one large company, two SME's, one research institute and one university lead to the following conclusions on appropriate exploitation:

- Result # 1: "Dried Biomass Pack": The CNR-ICVBC intends to develop and commercialise the Dried Biopack but at a small scale. However, for wider productions, there will be a need to find an industrial partner.
- Result # 2; # 3 and # 4 ECO-CEMENT Tiles, plaster and bedding mortar: The exploitation perspectives for ECO-CEMENT tiles, plaster and bedding mortar, will most likely consist on *licensing* the products to a third party.
- Result n# 5 "ECO-CEMENT Training course: It will be a mandatory requirement of Neapolis' Civil Engineering students this coming semester (starting February 2015).

The most significant result of this Task, and possibly the whole project, is the understanding by the consortium partners that the knowledge developed within this project is valuable and that there are large industries interested in further development of bio-cementation technologies. The production process developed within the project has been demonstrated to be very profitable and the products have a very low, and potentially positive, environmental impact which will be increasingly marketable and valuable.

The project has identified where further R&D activities would improve the product and process and the consortium partners have privately agreed to work together for the first year after the project to disseminate the project results and investigate other opportunities for R&D funding.

5 PUBLIC WEBSITE ADDRESS. RELEVANT CONTACT DETAILS.

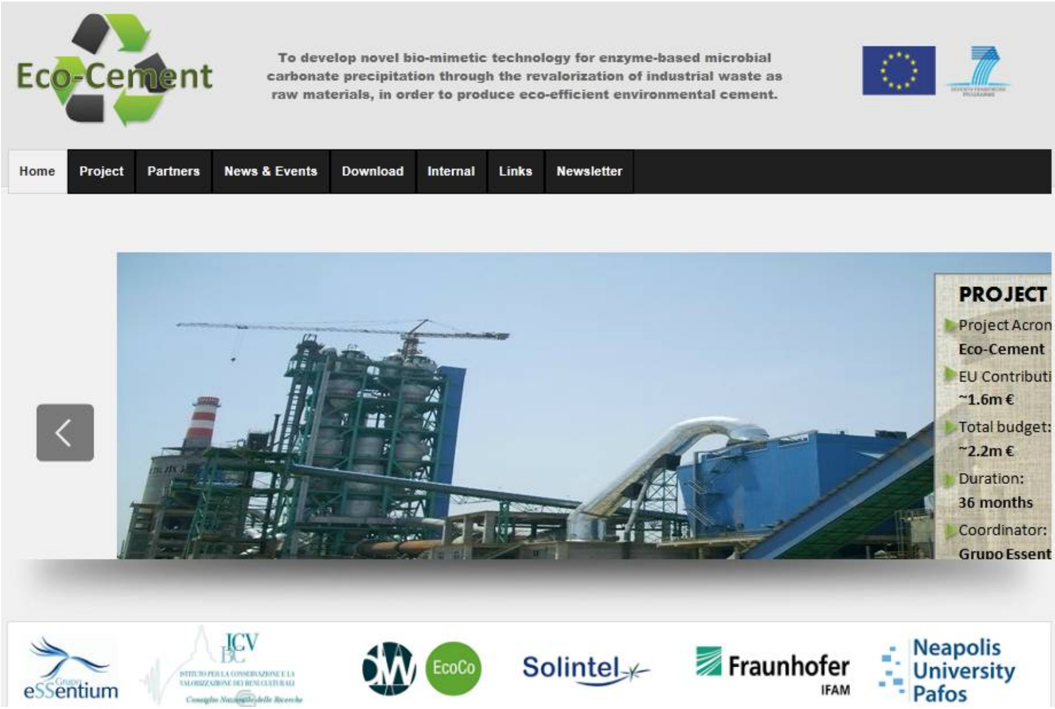
5.1 Public website

By M3 SOLINTEL developed the website that has been used as the main project dissemination tool. We have provided a website with the following content:

- Newsletter nº1 (March 2013), nº 2 (September 2013), and nº 3 (June 2014).
- Project brochures
- Project general presentations
- Bookmark for companies outside the consortium that have cooperated by supplying samples of waste material.

More material has been included while the project progressed, including:

- PU Deliverables from project work packages.
- Video showing the manufacturing process of ECO-CEMENT.
- Video TV channel “Euronews” about our project.
- Abstracts and posters presented in conferences to which we have attended to;
    - 12th SGA Biennale Meeting. Mineral deposit research for a high technology world. Uppsala, Sweden 12-15 August 2013. Organised by “Society for geology applied to Mineral Deposits”.
    - EUROMAT 2013 FEMS. European congress and exhibition on advanced materials and processes, Seville 8-13 September 2013.
    - ICEBE 2015: ECO-CEMENT was represented in the International Conference on Environmental and Bio-Engineering Conference on January 10-11 in Dubai 8UAE).
    - SAIE 2014: the first official presentation of ECO-CEMENT to an International audience took place at the 50^{th} Built Environmental Exhibition (SAIE), on the 25^{th} of October 2014 in Bologna.
- Newsline advertising the project events, such as the first project workshop.
- Press releases and scientific publications, magazine.
- We provided our website with a contact point in order to gather more information from relevant stakeholders.
- Education and training e-learning modules.
- Finally, the TV channel “Euronews” contacted the consortium in order to produce a report over the project. A link to this report is available at the website.



www.eco-cement.eu

Figure 24: The ECO-CEMENT website

5.2 Relevant contact details.

Table 11 Relevant Project contact details.

ORGANIZATION	CONTACT DETAILS
GRUPO ESSENTIUM	Mr. Juan Alvargonzález jalvargonzalez@essentium.com Grupo ESSENTIUM Avd. Quitapesares 11 Pol. Emp. Villapark 28670 Villaviciosa de Odón Madrid, Spain www.essentium.com
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SOLINTEL	Mr. Javier Royo javier.royo@solintel.eu SOLINTEL M&P S. L. Avda. De Jerez 33 28514 Nuevo Baztán (Madrid, Spain) www.solintel.eu
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